Scientific Excellence • Resource Protection & Conservation • Benefits for Canadians
Excellence scientifique • Protection et conservation des ressources • Bénéfices aux Canadiens

# A Review of Hydrocarbon Research and Monitoring Programs in the Department of Fisheries and Oceans

K.B. Yuen, P.D. Keizer, W.L. Lockhart, C.D. McAllister,
R.J. Paterson and J.F. Payne

Physical and Chemical Sciences Directorate
Department of Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

December 1988

Canadian Technical Report of
Fisheries and Aquatic Sciences
No. 1684

Fisheries and Oceans	Pêches et Océans

Canada

89-04771/

## Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

## Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences
1684

December 1988

# A REVIEW OF HYDROCARBON RESEARCH AND MONITORING PROGRAMS IN THE DEPARTMENT OF FISHERIES AND OCEANS

by

K.B. Yuen, P.D. Keizer, W.L. Lockhart, C.D. McAllister
R.J. Paterson and J.F. Payne

Physical and Chemical Sciences Directorate
Department of Fisheries and Oceans
200 Kent Street
Ottawa, Ontario
K1A 0E6

PUBLISHED BY:

Communications Directorate
Department of Fisheries and Oceans
Ottawa, Ontario
K1A 0E6

DFO/4277

©Minister of Supply and Services Canada 1989

Catalogue Number Fs 97-6/1684E
ISBN 0-662-17093-8
ISSN 0706-6457

Correct citation for this publication:

Yuen, K.B., P.D. Keizer, W.L. Lockhart, C.D. McAllister, R.J. Paterson and J.F. Payne. 1988. A review of hydrocarbon research and monitoring programs in the Department of Fisheries and Oceans. Can. Tech. Rep. Fish. Aquat. Sci. 1684: vii + 130 pp.

## TABLE OF CONTENTS

Page

CHAPTER 1 THE REVIEW

1.0 Introduction .......... 1
1.1 Background .......... 1
1.2 Objectives .......... 1
1.3 Scope of Study .......... 2
1.4 Review Team .......... 2
1.5 Context for Review .......... 2

CHAPTER 2 DFO'S MANDATE AND ROLE

2.0 Introduction .......... 4
2.1 The Mandate .......... 4
2.2 The Role .......... 5
2.2.1 Response to Hydrocarbon Spills .......... 5
2.2.2 The Growth of Oil and Gas Exploration Off Canada's Coasts .......... 5
2.2.3 Oil and Gas Development in Freshwater Drainages .......... 6
2.2.4 The Development of the Environmental Assessment and Review Process .......... 6
2.2.5 The Importance of DFO Expert Advice and Specifications .......... 6
2.3 Monitoring .......... 7
2.4 Emergencies .......... 8

CHAPTER 3 STATE OF SCIENTIFIC KNOWLEDGE

3.0 Introduction .......... 10
3.1 Biogeochemistry of Hydrocarbons .......... 10
3.1.1 General Description of Hydrocarbons .......... 10
3.1.1.1 Combustion Sources of Hydrocarbons .......... 10
3.1.1.2 Weathering .......... 10
3.1.2 Sources of Petroleum Hydrocarbons .......... 11
3.1.2.1 Seeps and Erosion .......... 11
3.1.2.2 Offshore Oil and Gas .......... 11
3.1.2.3 Marine Transportation .......... 12
3.1.2.4 Refineries and Distribution Facilities .......... 12
3.1.2.5 Runoff .......... 13
3.1.2.6 Use of Dispersants .......... 13
3.1.2.7 Atmospheric Input of Hydrocarbons .......... 13
3.1.2.8 Information Gaps .......... 15
3.1.3 Fate of Petroleum Hydrocarbons .......... 15
3.1.3.1 Physical Fates .......... 15
3.1.3.2 Information Gaps .......... 16
3.1.3.3 Biological Fates .......... 16
3.1.3.4 Information Gaps .......... 17

Page

CHAPTER 3 STATE OF SCIENTIFIC KNOWLEDGE (cont'd)

3.2 Ecological Effects of Hydrocarbons in the Aquatic Environment ........ 17
3.2.1 State of Knowledge ........ 17
3.2.1.1 Introduction ........ 17
3.2.1.2 Bacteria ........ 18
3.2.1.3 Phytoplankton ........ 18
3.2.1.4 Zooplankton ........ 18
3.2.1.5 Macrophytes (Kelps) ........ 19
3.2.1.6 Bottom Dwelling (Benthic) Invertebrates ........ 19
3.2.1.7 Fish ........ 19
3.2.1.8 Marine Mammals ........ 20
3.2.1.9 Communities and Ecosystems ........ 20
3.2.2 Research Capability ........ 21
3.2.3 Research Needs ........ 21
3.2.4 Problems in Meeting These Needs ........ 22
3.3 Monitoring ........ 23
3.3.1 Chemical Monitoring ........ 23
3.3.2 Biological Monitoring ........ 24
3.3.2.1 Biochemical Methods ........ 24
3.3.2.2 Cytology and Histopathology ........ 24
3.3.2.3 Physiological Methods ........ 25
3.3.2.4 Community Structure ........ 25
3.3.3 General ........ 25
3.3.4 Differences With Respect to Freshwater ........ 25

CHAPTER 4 RELEVANT EARP RECOMMENDATIONS

4.0 Introduction ........ 27
4.1 Review of Recommendations ........ 27
4.2 Discussion ........ 29

CHAPTER 5 CLIENT INTERVIEWS

5.0 Introduction ........ 31
5.1 Principal Research Needs ........ 31
5.2 Responses to Specific Questions ........ 32
5.3 Other Issues ........ 34
5.4 General Conclusions ........ 35

CHAPTER 6 ANALYSIS OF EXISTING PROGRAMS

6.1 Methodology ........ 36
6.2 Analysis ........ 37
6.2.1 National Issues and Perspectives ........ 37
6.2.2 Scientific Aspects ........ 38
6.2.3 Geographic Applicability ........ 39

Page

CHAPTER 7 REGIONAL PERSPECTIVES AND PRIORITIES

7.0 Introduction .................... 40
7.1 Newfoundland Region .................... 40
7.1.1 Past Programs and Achievements .................... 40
7.1.2 Immediate Issues and Needs .................... 41
7.1.3 Priorities for Research and Monitoring .................... 41
7.1.4 Program Strategies.................... 41
7.1.5 Research Needs for the Davis Strait and Labrador Areas .................... 42
7.1.5.1 Hydrocarbons in Fish and Seals in the Arctic .................... 42
7.1.5.2 Effect of Hydrocarbon Fumes on Seals .................... 43
7.1.5.3 Sublethal Effects on Arctic Fish .................... 44
7.1.5.4 Zoobenthic Effects: Special Perspective for the Arctic .................... 44
7.2 Scotia-Fundy and Gulf Regions Combined .................... 45
7.2.1 Past Programs and Achievements .................... 45
7.2.2 Regional Issues and Priorities .................... 47
7.3 Central and Arctic Region .................... 49
7.3.1 Introduction .................... 50
7.3.2 General Issues Related to Hydrocarbons .................... 51
7.3.3 Regional Issues .................... 51
7.3.3.1 Polycyclic Aromatic Hydrocarbons .................... 51
7.3.3.2 LRTAP (Atmospheric) and LRTOP (Oceanic) .................... 52
7.3.3.3 Arctic Oil and Gas Activity .................... 52
7.3.3.4 Oil Sands and Heavy Oils .................... 53
7.3.3.5 Spills .................... 53
7.3.3.6 "Natural" vs. Anthropogenic Hydrocarbons .................... 54
7.3.3.7 Coal and Coal Conversions .................... 55
7.4 Pacific Region .................... 55
7.4.1 Background .................... 55
7.4.2 Brief Outline of Past Hydrocarbon Efforts .................... 56
7.4.3 Continuing Concerns .................... 57
7.4.4 Research Issues and Priorities .................... 58

CHAPTER 8 CONCLUSIONS

APPENDIX A List of Clients Interviewed .................... 65
List of Questions Posed to Interviewees .................... 66
Summaries of Individual Interviews .................... 67

APPENDIX B Selected Key References .................... 73

Page

APPENDIX C Project Inventory .................................... 75

Part 1 List of Project Titles ................................ 76
Part 2 Project Budgets ...................................... 77
Part 3 Sources of Funding ................................... 78
Part 4 Geographic Applicability ............................. 79
Part 5 Scientific Aspects ................................... 80
Part 6 Project Sheets ....................................... 81

## ABSTRACT

Yuen K.B., P.D. Keizer, W.L. Lockhart, C.D. McAllister, R.J. Paterson and J.F. Payne. 1988. A review of hydrocarbon research and monitoring programs in the Department of Fisheries and Oceans. Can. Tech. Rep. Fish. Aquat. Sci. 1684 : vii + 130 pp.

The review was carried out in 1987-88 to access the adequacy of current DFO hydrocarbon research programs. The objective was to determine whether any changes in priorities or resource allocations would be warranted.

The review comprises a brief summary of current knowledge on the topic along with analyses of existing DFO programs by region. Brief analyses of relevant EARP recommendations and comments from selected clients are included.

A number of areas are identified for priority research attention but no major shifts in priority are proposed. Suggestions for better communication of research results are made. Resource levels were assessed as adequate; however, too high a proportion of the funding is derived from external (non-DFO) sources.

## RÉSUMÉ

Yuen K.B., P.D. Keizer, W.L. Lockhart, C.D. McAllister, R.J. Paterson and J.F. Payne. 1988. A review of hydrocarbon research and monitoring programs in the Department of Fisheries and Oceans. Can. Tech. Rep. Fish. Aquat. Sci. 1684 : vii + 130 pp.

La revue fut effectuée en 1987-88 pour évaluer la situation des programmes de recherche du MPO sur les hydrocarbures. L'objectif était de déterminer si des changements des priorités ou des allocations des ressources seraient requis.

La revue comprend un bref résumé des connaissances actuelles sur le sujet de même qu'une analyse des presents programmes du MPO, par région. Un analyse sommaire des recommendations pertinentes du PEEE ainsi que les commentaires de certains clients sont également inclus.

Certains domaines de recherche nécesseitant une attention particulière sont identifiés, mais aucune modification majeure aux prioritée n'est proposée. On fait en autre quelque suggestions afin d'améliorer la communication des résultats de recherche. Quant aux niveaux de ressources, on estime qu'ils sont adéquats. Néanmoins, la proportion des fonds provenant des sources externes au MPO est jugée trop élevée.

# CHAPTER 1

# THE REVIEW

## 1.0 Introduction

### 1.1 Background

For nearly two decades, since the oil tanker ARROW ran aground on the shores of Nova Scotia in 1970, the Department of Fisheries and Oceans has carried out an extensive research program on the behaviour and biological impacts of released petroleum hydrocarbons. Initially, this research was prompted by public and governmental concern for catastrophic oil spills and the routine discharge of tank washings, as well as oil refinery effluents. Over time, the concern for oil spills has extended to offshore exploration drilling on the Canadian continental shelf and in the Arctic. More recently, specific concerns have emerged regarding the use of oil-based muds, the use of additives during drilling and the potential impacts of production.

Over the past decade in particular, a number of hydrocarbon exploration, development and transportation project proposals have been referred to the Environmental Assessment and Review Process. Almost invariably EARP Panels, in their final reports, have called upon DFO to conduct research in a number of priority areas, including the fate and effects of petroleum hydrocarbons.

Notwithstanding the substantial level of hydrocarbon related activities underway in DFO, additional demands remain unfulfilled. It is not only a question of scarce scientific resources during a period of severe fiscal restraint but there is emerging, as well, a wide range of toxic chemical problems, many of which may in fact create greater threats to the health of fish, fish habitat and ecosystems than the dangers posed by petroleum hydrocarbons. The West Coast may be an exception, where petroleum hydrocarbons appear to present a higher risk than do other types of hydrocarbon pollution. As well, serious problems are emerging with respect to other types of hydrocarbons, particularly polynuclear aromatic hydrocarbons (PAHs).

In 1986, after the Panel on West Coast Offshore Exploration had called upon DFO to carry out additional hydrocarbon research and monitoring, it became timely to assess the overall departmental priorities, programs and strategies in this subject area. Accordingly, the ADM, Science initiated this review of DFO programs.

### 1.2 Objectives

The objectives of this study are:

TO REVIEW DFO HYDROCARBON POLLUTION RESEARCH AND MONITORING PROGRAMS, AND TO RECOMMEND APPROPRIATE LONG TERM STRATEGIES.

The components of this review will include:

- a summary of past DFO programs and achievements and an assessment of present capabilities and state of knowledge;
- an inventory and analysis of present and planned programs;

- the identification of present and future priorities for research and monitoring and the development of program strategies.

## 1.3 Scope of Study

The scope of the study extends to:

- all forms of hydrocarbon pollution, including such sources as offshore oil and gas development, shipping, fly ash, sewage sludge and the production of synthetic fuels from coal, tar sands and shale;

- all phases of the oil pollution problem including basic chemistry, analytical methods, sources and fate and effects;

- effects upon aquatic ecosystems generally, including both freshwater and marine ecosystems, as well as fish and fish habitat;

- both research and monitoring, and

- the roles and responsibilities of DFO in these matters.

## 1.4 Review Team

The review team comprised members from each region except the Gulf Region. These representatives were:

| | |
|---|---|
| K.B. Yuen (Chairman) | Headquarters |
| R.J. Paterson (Secretary) | Headquarters |
| J.F. Payne | Newfoundland Region |
| P.D. Keizer | Scotia-Fundy Region |
| Y. Vigneault | Quebec Region |
| W.L. Lockhart | Central and Arctic Region |
| C.D. McAllister | Pacific Region |

In the case of Gulf Region, where there is no existing Physical and Chemical Sciences Program, regional perspectives on needs and priorities were combined with inputs from the Scotia-Fundy Region. The review also received support from a number of DFO staff across the country, most notably R.J. Wiseman, J. Vandermeulen, J.S. Loch, J. Piuze and J. Cooley, amongst others. W.D. McKone, Headquarters, was also a member of the review team during the early stages.

Finally, the team is indebted to Mrs. S. Mousseau for typing this manuscript.

## 1.5 Context for the Review

DFO's interests and responsibilities extend far beyond hydrocarbons to all manner of contaminants which may affect fish, fish habitat and aquatic ecosystems generally. Since the area of examination here is restricted to matters relevant to hydrocarbons, the results of this review are limited to identifying the nature and extent of hydrocarbon issues and the priority of specific areas of hydrocarbon research relative only to other areas of hydrocarbon research. It was not within the team's terms of reference to recommend relative priorities among research projects on hydrocarbons and on other types of contaminants.

Subsequent to the initiation of this review, and as part of the infrastructure for managing DFO's newly integrated Science Program, the department established a Working Group on Toxicology and Contaminants Science, reporting to the Physical and Chemical Sciences Subcommittee of the National Science Directors Committee. That working group has as a principal task the development of a long term contaminants science program strategy for DFO. Clearly, this overall strategy provides the broader context within which DFO's hydrocarbon programs must fit. It was decided that the output of this hydrocarbon review would provide one component of input into the contaminants strategy. However, this hydrocarbon review is to continue separately to a logical conclusion, since it provides a test case to develop, in detail, the study methodology to be applied to the broader study. Finally, it is the larger contaminants study which will be able to determine the appropriate level and priority of hydrocarbon research topics relative to that for other contaminants. Indeed, it may well be that certain constraints to our ability to predict, for example, population level effects of hydrocarbon contamination, are a reflection of a general deficiency in the state of contaminants science or in our knowledge of population dynamics. The optimum strategy may not necessarily be to address the hydrocarbon problem specifically.

It is of note that DFO's hydrocarbon research program has made substantial contributions internationally to the understanding of the fate and effects of hydrocarbons in the aquatic environment. Many DFO scientists are international authorities on various aspects of the subject. It is perhaps unavoidable that this report will be perceived by some as being somewhat negative and critical. However, while past achievements are touched upon briefly in Chapter 7, it must be recognized that the prime objective of the study is to analyze present programs and to recommend future directions for research. It is hoped that the result will be viewed as a constructive assessment which will lead to a strengthening of the program, both nationally and regionally.

# CHAPTER 2

## DFO'S MANDATE AND ROLE

### 2.0 Introduction

Neither DFO's mandate nor its role with respect to hydrocarbon pollution research have been described anywhere in a concise and tidy manner. Rather, with the department's overall legislative mandate as a base, the role in this area has evolved and developed to a state which today is well recognized and accepted. Inevitably, since specific events have lent shape to that evolution, centres of excellence or specialty have developed in certain laboratories while others remain less well endowed.

### 2.1 The Mandate

DFO's overall mandate is derived from the Constitution Act, 1867 and the Department of Fisheries and Oceans Act, 1979, with a part of its ocean science mandate being derived from the Resources and Technical Surveys Act (Government Organization Act), 1966.

The department's major legislative responsibility is the Fisheries Act and the habitat sections of that Act provide both the mandate and the rationale for research on pollutants. Section 30 prohibits the destruction of fish by any means other than fishing, except as authorized by the Minister or pursuant to regulations under the Act. Section 31 prohibits the conduct of any work or undertaking which results in harmful alteration, disruption or destruction of fish habitat. Section 33 is designed to control the deposit of deleterious substances into waters frequented by fish. Fish habitat includes most of the marine and fresh waters of Canada.

Under the Department of Fisheries and Oceans Act, 1979, DFO is assigned responsibilities for marine science. This has evolved to include the conduct of research and monitoring and the provision of information and advisory services relating to marine contaminants generally, including hydrocarbons and their impacts upon the functioning of marine ecosystems.

Certain federal regulatory agencies have mandates which include protection of the aquatic environment (e.g. DIAND, COGLA, DOT, DOE). DFO provides ongoing advice to these agencies in order to ensure that the requirements of the Fisheries Act are met. Environment Canada and DFO share responsibilities for the implementation of Section 33. The division of these responsibilities is based upon the Lucas-Weir memorandum of 1971, prepared when the Environmental Protection Service was first established, which made EPS responsible for the management of discharge levels and for monitoring within a defined 'zone of influence' around the discharge pipe. The then Fisheries and Marine Service was made responsible for monitoring and research outside the zone of influence i.e. in the broader receiving waters. That sharing of responsibilities was confirmed and redefined in 1985 in a DOE/DFO Memorandum of Understanding concerning Section 33.

## 2.2 The Role

The department's role in research on hydrocarbons has been influenced by three major factors or series of events, each occurring in parallel:

### 2.2.1 Response to Hydrocarbon Spills

The grounding of the 'Arrow' in Chedabucto Bay in 1970 demonstrated the Canadian government's limited capability both to respond to a moderately large oil spill and to predict its effects on the environment. The report of the Scientific Coordinator to the Task Force on the cleanup contained a number of recommendations, several of them pertaining to research needs. One of these urged the establishment of a permanent evaluation unit responsible for dealing with spills and providing, among other things, a focus for coordination and planning of a national program of research.

A series of follow-up studies provided the basis for an ongoing program at the Bedford Institute on hydrocarbon pollution and its effects. DFO scientists visited and studied the site of the 'Amoco Cadiz' spill in 1978 and a small team visited the Texas coast following the IXTOC-1 spill in 1979. Each of these spills, and others, served to maintain public concern for oil pollution and to act as reminders of the need for a Canadian research capability in this area. A substantial research effort was initiated in response to the Kurdistan spill in 1979 and to several lesser spills in the intervening years.

Over a period of years, the federal government has established and developed a spill response organization involving a number of different agencies. In several regions, scientific advice is provided to an On Scene Commander through a Regional Emergency Response Team (REET) chaired by Environment Canada. DFO plays a major role on these teams as an important source of physical marine data, with a capability for spill tracking and oil spill trajectory modelling, and as a major source of advice on the potential effects of a spill on aquatic organisms and fisheries and on sensitive areas.

### 2.2.2 The Growth of Oil and Gas Exploration Off Canada's Coasts

Exploration for oil and gas in Canadian offshore waters began in earnest during the mid-1960s. However, it was not until the 1970s that the risks to fishery resources were recognized and efforts made to ensure that these resources were adequately protected. Interdepartmental mechanisms were established to provide advice to the regulatory agencies (initially EMR and DIAND, and more recently COGLA) in order to ensure compliance with the requirements of the Fisheries Act.

DFO's role in providing regulatory agencies with a knowledge of marine resources and the potential effects of hydrocarbons on them, has become well established during the past 10-15 years. It was confirmed in the 1982 Memorandum of Understanding with COGLA and will soon be recognized in a Memorandum of Understanding with the recently established Canada-Newfoundland Offshore Petroleum Board. For waters offshore Nova Scotia, DFO advice is channelled through an Environmental Coordinating Committee under the auspices of the Canada-Nova Scotia Oil and Gas Board. For the North, advice is channelled through the Arctic Waters Advisory Committee (AWAC) which provides its advice to DIAND. A similar regional mechanism is likely to be established soon for dealing with drilling off the northern coast of B.C.

The rate at which offshore oil and gas production will proceed is difficult to predict and will depend much upon world oil prices. Similarly, the possible effect of the proposed free trade agreement with the U.S. on the rate of development remains an unknown quantity.

### 2.2.3 Oil and Gas Development in Freshwater Drainages

Production of conventional oil and gas from reserves in Alberta and Saskatchewan will continue, with rates dependent upon prices, trade agreements, and the success of exploration activity. The principal growth in fossil fuel production is likely to be the expansion of production of synthetic crude from oil sands in Alberta, and of heavy oil production and upgrading on the Alberta/Saskatchewan border. Mackenzie Valley production was recently expanded six-fold with completion of the new pipeline from Norman Wells to Alberta. The pipeline is scheduled to be expanded and extended to the Mackenzie Delta in order to accommodate future production there.

### 2.2.4 The Development of the Environmental Assessment and Review Process

Since the establishment of the Environmental Assessment and Review Process (EARP) in 1974, DFO scientists have played a major role in environmental impact assessment. DFO (and the Fisheries & Marine Service before it) has been seen as the major source of expertise on marine science and on the protection of fishery resources and the aquatic environment. Advice has been provided on a large number of projects of varying size along with recommendations for reducing or avoiding adverse impacts.

A number of projects with a potential for aquatic environmental impacts have been referred to environmental assessment panels, usually involving offshore exploration and development, transportation or port development. DFO scientists have appeared before these panels, frequently presenting a position statement and responding to questions from panel members, the proponent and the general public. These activities have done much to enhance the public perception of DFO as a prime source of expertise on aquatic pollution and on the effects of industrial developments on aquatic resources. On several occasions panels have recommended that further research be carried out on particular topics, as outlined in Chapter 4.

### 2.2.5 The Importance of DFO Expert Advice and Specifications

The above three areas of activity have clearly done much to foster the development and recognition of DFO's role in the control of aquatic pollution, particularly by oil and hydrocarbons. Oil can be a very visible pollutant and for that reason engenders more public concern than other less visible materials. This has helped to maintain the profile of oil pollution and the need for continuing research on it.

DFO has a major responsibility as a manager of living aquatic resources. An important facet of this management is the protection of these resources and the habitat on which they depend from adverse impacts. Such protection is achieved in a variety of ways. Advice may be given to regulatory agencies on quantities or concentrations of pollutants deemed to be acceptable in waste streams. Such requirements may be for general application or may be site-specific. DFO may recommend other methods of waste management or control or may advocate measures to reduce the chance of an accident or to minimize the adverse effects of a spill (e.g. contingency planning).

Such advice must be based on good science if it is to achieve its objective and to be defensible. Some of this needed information can be obtained from the scientific literature and from scientists in other countries or agencies. However, there are many areas where problems are local or regional in nature, which concern species with limited distribution or which have not been addressed by scientists from elsewhere, notably problems involving ice-covered northern waters. For these reasons, DFO needs not only to maintain a core of national expertise in hydrocarbon pollution but also a strong capability in most regions in order that site-specific and regional issues can be adequately addressed.

Advice has recently been provided on such topics as guidelines for the use of oil-based drilling muds, the use of drilling fluid lubricants and guidelines for drilling and production wastes. This advice is rendered through the Canadian Environmental Committee on Petroleum Activities (CECPA). Another topic which is requiring increasing attention is the provision of expert advice for court cases, most commonly for violations of the Fisheries Act.

In summary, DFO's mandate with respect to hydrocarbon pollution is contained within the legislation defining the department's broad national mandate. Its role in this area has evolved and developed to the point that the department is now recognized, both by other agencies and by the public, as a prime source of expert advice on hydrocarbon pollution and its effects on aquatic life.

## 2.3 Monitoring

The objective of compliance monitoring is to measure compliance with a set of specific conditions, generally imposed as maximum permissible levels or concentrations of identified chemicals in effluent streams. The objective of effects monitoring is to determine how given wastes become distributed in the environment and what effects they may have on the resident biota.

For specific industrial activities in or adjacent to the aquatic environment the proponent bears the major responsibility for compliance monitoring. In contrast, DFO monitoring programs are carried out in order to assess changes in water quality or habitat and to determine the effect of such changes on fish populations and aquatic biota. Proponents are not normally required to carry out effects monitoring studies except where they are using untested or unproven techniques, such as when using oil-based drilling muds for offshore drilling.

Monitoring the levels of various hydrocarbons in the aquatic environment is an expensive but necessary task. This is because most hydrocarbon wastes come from a variety of sources and not from single-source, regulated effluents. Federal responsibility for such monitoring is shared with Environment Canada. However, the challenge is to carry it out in a cost-effective manner while ensuring that the results are statistically defensible.

Where a proponent is required to conduct an effects monitoring program, DFO may play a major role in designing it.

DFO carries out monitoring programs for hydrocarbons with the following objectives in mind:

(i) to prescribe or revise regulations and standards applicable to specific industrial operations;
(ii) to ensure that monitoring programs for implementation by industrial proponents will be effective, and
(iii) to establish regional trends.

Recommendations for specific operating conditions are submitted to the appropriate regulatory agency (e.g. DOE, COGLA, DIAND) for implementation under the relevant legislation.

Each of the above supports and relates directly to DFO's responsibility to manage and protect fish habitat.

## 2.4 Emergencies

DFO has a major role to play not only in the event of a spill or accident involving hydrocarbons but also in ensuring that there are adequate measures in place to prevent or prepare for such occasions.

Oil companies exploring in offshore waters must submit contingency plans to the appropriate regulatory agency describing the actions that will be taken in the event of an emergency. Such plans are subject to review by DFO staff. Other industrial operations involving hydrocarbons, such as marine transportation, refineries or oil sands plants, may not have to meet such requirements. Nevertheless, the risks of an accident are there. In all situations, government must be prepared to assume responsibility or to play a major support role in order to ensure the protection of both publicly and privately owned resources. DFO, as a government agency with major responsibilities for the aquatic environment, must have its own response plans in place. These will ensure that the department can respond quickly and effectively in an emergency in full support of the On Scene Commander and in close cooperation with other responsible parties. At the present time DFO's response plan is in draft form and revisions are needed so that the plan will reflect the new departmental organization.

In the event of a spill involving hydrocarbons DFO has several different and distinct responsibilities. First, it provides the oceanographic information needed both to predict the path of the spilled material and to plan the response operation. In certain areas the department also has an in-house capability for spill-tracking. In addition, advice is provided to the On Scene Commander concerning the protection of fishery resources, the fishery and fish habitat. This is often achieved through a Regional Environmental Emergencies Team comprising representatives of all agencies with environmental interests. In such instances decisions may have to be taken on areas of priority for the application of protective measures (e.g. use of booms to cordon off a bay). These decisions are made based on a knowledge of the fishery resources and habitat at risk, the probable behaviour of the oil and any predicted adverse effects on the fishery.

An oil spill may provide an excellent occasion for opportunistic research. In order to benefit from such a situation scientific staff must be prepared so that valuable time is not lost before studies are initiated.

It should be clear from the above that if DFO is to act in a responsible manner during an emergency and to provide constructive advice to an On Scene Commander it must possess a good knowledge of the important regional fishery resources and their behaviour on a seasonal basis. It is particularly important that the whereabouts of eggs and juveniles are known, since these are often the most vulnerable life stages. The location of fishing activities is also needed to avoid tainting of product and fouling of fishing gear. By this means, sensitive areas can be identified and priorities for protective action established. A good understanding is also needed of the behaviour of different hydrocarbons in water and their relative toxicities under various conditions. This knowledge is similar to that needed for the provision of advice on broader measures to protect the aquatic environment, including the management and control of effluents containing hydrocarbons.

# CHAPTER 3

# STATE OF SCIENTIFIC KNOWLEDGE

## 3.0 Introduction

The chemistry and physics of hydrocarbons are complex. The behaviour of hydrocarbons in the aquatic environment and their fate and effects on aquatic organisms is a difficult subject. A very brief overview is included here to provide some background for readers less familiar with the subject area. More complete treatments can be found in the references listed in Appendix B.

It is convenient to categorize the different aspects of hydrocarbon science along the lines of:

- biogeochemistry of hydrocarbons;
- ecological effects of hydrocarbons in the aquatic environment.

The current state of knowledge of each of these components is discussed below.

## 3.1 Biogeochemistry of Hydrocarbons

### 3.1.1 General Description of Hydrocarbons (Principally Petroleum)

Crude oils contain thousands of different chemical compounds produced during the process of petroleum formation. Commonly occurring types of compounds include alkanes, cycloalkanes and aromatics, both alkylated and parent structures. Heterocyclic compounds containing N, S, and O groups (NSO compounds) are also present. In addition, petroleum contains a significant fraction of material of higher molecular weight consisting of both hydrocarbons and NSO compounds called asphaltenes. These compounds, consisting of 10-20 fused rings with aliphatic and naphthenic side chains, contribute significantly to the properties of petroleum. Refined petroleum products contain all the hydrocarbon classes mentioned but have narrower boiling ranges. In addition, refining operations may generate new compounds such as alkenes, cycloalkenes and higher concentrations of branched compounds and parent PAHs.

#### 3.1.1.1 Combustion Sources of Hydrocarbons

Particulate matter in urban air contains saturated and aromatic hydrocarbons formed during the pyrolysis of any carbon-based fuel. Aromatic hydrocarbons from combustion sources are characterized by lesser degrees of alkylation than aromatics from petroleum, with the degree of alkylation being temperature dependent. Hydrocarbons produced in internal combustion engines are also commonly enriched in nitro substituted PAH. Saturated hydrocarbons are also emitted as a result of combustion processes; these may be similar in composition to those found in weathered petroleum.

#### 3.1.1.2 Weathering

During weathering, some features associated with petroleum may be reduced in importance while other new features may appear. Important changes include evaporation of low boiling compounds and an increased importance of naphthenic compounds and highly branched aliphatic and polycyclic-aliphatic structures.

Weathered petroleum also contains the oxidation products of both photochemical and microbial oxidation. Sunlight can be expected to initiate a variety of reactions producing ketones, aldehydes, acids, and sulfoxides. In addition, polymerization products from photolysis affect the chemical and physical properties of oil such as emulsification rate. Microbial oxidation can generally be expected to result in the formation of the same class of reaction products as does photolysis. However, microbial processes are more selective. Overall, the relative importance of photolysis and microbial oxidation remains poorly understood.

### 3.1.2 Sources of Petroleum Hydrocarbons

The five major sources of oil input to the oceans are natural oil seeps and erosion of sedimentary rock formations, offshore hydrocarbon production, marine vessel operations, atmospheric inputs and municipal and industrial wastes and runoff. These are summarized in Table I (extracted from the 1985 National Research Council's report "Oil in the Sea", p. 82). The figures are, however, global ones and it should be recognized that certain inputs will have much greater significance regionally or locally than they have globally.

#### 3.1.2.1 Seeps and Erosion

More than 190 submarine oil seeps have been found in coastal and inland areas of the world, with most of these occurring in groups or clusters within the margins of continental shelves. In Canada, natural oil seepage has been observed off the coasts of Labrador and Newfoundland, as well as along the north coast of Baffin Island in the Canadian Arctic. It can be assumed that substantially more seeps exist in offshore sedimentary basins than have been documented. On a worldwide basis estimates of the rate of seepage range from 0.02 to 0.2 million metric tons per year (mta), which represents about 6% of the total annual input of petroleum hydrocarbons to the oceans. There is considerable uncertainty regarding the importance of erosional inputs of petroleum but these are estimated to be around 1% of total inputs.

#### 3.1.2.2 Offshore Oil and Gas

The major source of oil input to marine waters around offshore facilities is produced water, with anywhere from zero to 0.8 barrels being produced per barrel of crude. Although oil concentrations in produced waters vary substantially, depending on both source and treatment, concentrations in the 50-70 ppm range are common. The amount entering the oceans from produced waters is estimated to range from 0.0075 to 0.0115 mta.

Minor accidental spills ( 50 barrels) occur during routine operations at offshore production platforms. Estimated inputs range from 0.0027 mta to 0.0038 mta, equivalent to 6% of all oil inputs associated with offshore oil and gas production activities.

The majority of the petroleum entering marine environments at offshore production operations results from major oil spills and blowouts ( 50 barrels), with rates estimated to be 0.03 to 0.05 mta. In this respect, an added cause for concern in Canada is the difficulty of controlling a blowout under harsh winter conditions. Such conditions also contribute to the risk of such an accident occurring.

Small quantities of diesel oil may be used during drilling to lubricate sticking drill stack equipment. Some of this oil is inevitably released to the environment. A government/industry task force has recently been formed to assess the effects on marine organisms and to recommend approaches which will lead to a reduction in any adverse effects.

Diesel oil has also been used in the North Sea for some years as the base fluid for drilling muds. Use of such muds has not been permitted in Canadian waters on account of the toxicity of the oil. However, new low toxicity oil-based muds are being permitted on a limited basis. Such muds increase the efficiency of drilling operations, particularly in certain formations, and can significantly reduce drilling time.

Cuttings from the use of oil-based muds may be released into the sea. Despite special washing procedures these cuttings carry with them some hydrocarbons adsorbed to the mud particles. The cuttings may adversely affect the benthic environment, both by creating a physically impermeable layer and through slow release of toxic hydrocarbons. The quantities involved do not warrant serious concern during most exploratory operations but can be of real concern at an offshore production facility where a large number of wells may be drilled from a single platform.

#### 3.1.2.3 Transportation

Almost half of the oil entering the oceans results from marine transportation activities (1.0-2.6 mta), while just under half of this input is from operational discharges from tankers. The remainder is distributed among terminals, dry-docking, bilges, fuel oil from ships and accidental spills from ships. Implementation of the International Convention on Marine Pollution 1973 (MARPOL) and its 1978 Protocol is currently achieving a reduction in this pollution source. The main areas of Canadian concern are the international transportation routes (e.g. Alaska - U.S. West Coast) and the major import-export routes.

Oil occasionally enters fresh waters as a result of breaks in overland pipelines, particularly near stream crossings, which can have locally damaging effects.

#### 3.1.2.4 Refineries and Distribution Facilities

Much of Canada's refining capacity is localized at sites on a few freshwater drainages (Nelson, Mackenzie, St. Lawrence) and on the coasts (Vancouver, St. John, Halifax, Come-by-Chance). There are also U.S. refineries located very close to Canadian waters. There have been instances where effluents from refineries have caused tainting in fish. Clearly, the question of the most appropriate technology for regulating refinery effluents, particularly under winter conditions, should be reviewed. It may prove desirable to establish different effluent limits for different seasons and discharge points.

Underground storage tanks of refined petroleum products frequently leak, with resulting contamination of shallow ground water. This is a continuing source of contamination of water wells and of sites where the water returns to the surface.

### 3.1.2.5 Runoff

The estimated input of petroleum hydrocarbons into the marine environment from municipal and industrial wastewater, urban and river runoff and ocean dumping ranges from 0.60 to 3.1 mta. Municipal wastewater is the largest contributor, followed by industrial discharge and urban runoff. In total, these inputs account for over 35% of the hydrocarbons entering the oceans or almost twice those resulting from accidental spills.

A common source seems to be the practice urban Canadians have developed of changing the oil in their cars at home, with resulting disposal of the old oil down municipal sewers. In many instances the storm sewers discharge directly to the nearest stream with no treatment, and it is these sewers that often receive the oil because of their convenient locations. Probably only education and some incentive to turn in the old oil can limit this type of source but it can provide a continuing input of hydrocarbons to urban waters and these waters are among the most highly valued in Canada for recreational use. Also, used oils are more highly mutagenic than the same oils before use because of the increase in PAH content during engine operation.

### 3.1.2.6 Use of Dispersants

Dispersants are among the various tools available for treatment of an oil spill. They are a means of controlling a spill and not a means of cleanup since oil is merely transferred from the water surface into the water column. Dispersants in current use are much less toxic in themselves than those in use a few years ago. However, the effect of their use is to increase the exposure of many aquatic organisms to hydrocarbons. In principle, this is undesirable; nevertheless, the application of dispersants may be warranted under certain circumstances. Generally these circumstances occur (a) when resources which are concentrated on the water's surface are threatened (e.g. flightless seabirds) or (b) when use of dispersants will reduce the risk of damage to more valuable resources or amenities which are closer inshore, such as fish eggs and larvae or sandy beaches important to tourism.

DFO has participated in several field trials involving dispersants, one of particular note being the Baffin Island Oil Spill project which tested the behaviour and effectiveness of dispersants in an Arctic environment.

### 3.1.2.7 Atmospheric Input of Hydrocarbons

The estimated range of atmospheric input of hydrocarbons into marine environments is 0.05-0.50 mta. Coastal waters probably receive the highest input of airborne hydrocarbons, with concentrations decreasing away from coasts. The primary pathway for this input is expected to be removal of particulate material in the atmosphere by rain, while secondary pathways involve direct deposition of atmospheric particulates, removal and deposition of trace gases by precipitation, and direct gas exchange with the ocean. Precise estimation of the atmospheric input of hydrocarbons to the ocean will require information on the inputs of various components of petroleum into the sea surface and further understanding of the reaction products, pathways, and rates of transformation of these compounds in the atmosphere.

**TABLE 1: Input of Petroleum Hydrocarbons Into The Marine Environment (mta)**

| Source | Probable Range | Best Estimate[a] |
|---|---|---|
| Natural sources | | |
| Marine seeps | 0.02-2.0 | 0.2 |
| Sediment erosion | 0.005-0.5 | 0.05 |
| (Total natural sources) | (0.025)-(2.5) | (0.25) |
| Offshore production | 0.04-0.06 | 0.05 |
| Transportation | | |
| Tanker operations | 0.4-1.5 | 0.7 |
| Dry-docking | 0.02-0.05 | 0.03 |
| Marine terminals | 0.02-0.03 | 0.02 |
| Bilge and fuel oils | 0.2-0.6 | 0.3 |
| Tanker accidents | 0.3-0.4 | 0.4 |
| Non-tanker accidents | 0.02-0.04 | 0.02 |
| (Total transportation) | (0.95)-(2.62) | (1.47) |
| Atmosphere | 0.05-0.5 | 0.3 |
| Municipal and industrial wastes and runoff | | |
| Municipal wastes | 0.4-1.5 | 0.7 |
| Refineries | 0.06-0.6 | 0.1 |
| Non-refining industrial wastes | 0.1-0.3 | 0.2 |
| Urban runoff | 0.01-0.2 | 0.12 |
| River runoff | 0.01-0.5 | 0.04 |
| Ocean dumping | 0.005-0.02 | 0.02 |
| (Total wastes and runoff) | (0.585)-(3.12) | (1.18) |
| **TOTAL** | **1.7-8.8** | **3.2** |

[a] The total best estimate, 3.2 mta, is a sum of the individual best estimates. A value of 0.3 was used for the atmospheric inputs to obtain the total, although this best estimate is only a center point between the range limits and cannot be supported rigorously by the data and calculations used for estimation of this input.

Extracted from: Oil in the Sea - Inputs, Fates, Effects 1985, U.S. National Research Council (National Academy Press, Wahsington) 601 pp.

mta: million metric tons per annum.

#### 3.1.2.8 Information Gaps

Information gaps exist in the following areas: (a) the extent of submarine seepage of petroleum, (b) hydrocarbon levels in vapor, particulates and rain over the oceans, (c) inputs from municipal, industrial and runoff sources, (d) hydrocarbon photochemistry and solubility data, especially pertaining to air-sea exchange processes. Each of these need to be examined in a Canadian context. In particular, natural seeps deserve attention both as sites for the study of fate and effects and as situations involving chronic hydrocarbon contamination. They may also be used in the assessment of the possible beneficial contribution to nutrient content at certain locations.

### 3.1.3 Fate of Petroleum Hydrocarbons

#### 3.1.3.1 Physical Fates

Several critical physical processes are important when considering the fate of petroleum in the marine environment. These include evaporation, dissolution, vertical dispersion, emulsification and sedimentation. Involved in all of these processes are chemical factors including chemical transformation and photochemical oxidation.

Advection and spreading are important processes affecting the fate of spilled oil. Predictions of the rate of spreading and thickness of the slick based on complex mathematical modelling of these processes are generally unreliable because of the wide spectrum of oil types and the changing environmental conditions occurring during a spill. The best estimate of advection at the present time is that surface drift is 3-4% of wind speed.

Evaporation of oil is another important process, accounting for up to one- to two-thirds of the mass lost. Evaporation of various hydrocarbons from aqueous solution is also important. However, the predictability of evaporative behaviour is difficult due to the complexity of the oil and uncertainties in solubility and other thermodynamic data for individual compounds. Dissolution is considerably less important than evaporation in determining the fate of spilled oil because of the low aqueous solubility of most components.

The movement of oil into the water column is important because it determines the lifetime of a slick. The primary mechanism for the process is believed to be propulsion by surface turbulence of oil into the water column as a "shower" of oil droplets. Modelling awaits an understanding of the exact mechanism for this process.

Our present knowledge of atmospheric photochemistry suggests that much of the oil that evaporates is photochemically oxidized in the atmosphere. In surface water, photochemical oxidation may be important, taking place within a time scale of minutes to days. In addition, reaction products may be more or less toxic than their precursors.

Emulsification and mousse formation arise from physical mixing due to wave turbulence when oil is released into the sea and involves surface-active compounds (possibly asphaltenes, porphyrins, and other nitrogen, sulfur, and oxygen compounds). Products of photochemical and microbial oxidation also can serve as surfactants, but mousse formation may slow bacterial action, evaporation and dissolution.

Sedimentation of spilled oil takes place primarily through sorption on particulates or by incorporation into fecal matter. Weathering processes increase the density of floating oil and, when this occurs, incorporation into particles will eventually cause an increase in density above that of seawater so that the oil sinks below the surface into the water column and, in some cases, eventually to the sediments. In nearshore areas oil is entrained in sub- and intertidal sediments.

Hydrocarbons are generally more soluble in freshwater than in seawater; for example, Sutton and Calder (ES&T, 8, 654-657, 1974) gave the solubilities for several alkanes (ppb) below:

| Hydrocarbon | Solubility Distilled Water | Solubility Seawater |
|---|---|---|
| Dodecane ($C^{12}$) | 3.7 | 2.9 |
| Tetradecane ($C^{14}$) | 2.2 | 1.7 |
| Hexadecane ($C^{16}$) | 0.9 | 0.4 |
| Octadecane ($C^{18}$) | 2.1 | 0.8 |
| Eicosane ($C^{20}$) | 1.9 | 0.8 |
| Hexacosane ($C^{26}$) | 1.7 | 0.1 |

This difference can be expected to be reflected in correspondingly different partitioning of hydrocarbons to adsorptive surfaces like aquatic organisms or sediment particles. We might expect hydrocarbons to be somewhat more mobile (less likely to be adsorbed) in freshwater, but, to our knowledge, this has not been directly tested.

The Arctic presents special problems since, because of low temperatures and extensive ice coverage, oil may persist in the environment for extended periods. Oil may stay trapped under ice cover for many months or may aggregate in leads and open water areas where it can pose a threat to marine mammals such as seals.

### 3.1.3.2 Information Gaps

Significant information gaps exist in the following areas: (a) thermodynamic data on hydrocarbons and their congeners (for development of predictive models), (b) mechanisms of vertical dispersion of oil, (c) significance of the by-products of photooxidation, and (d) mechanisms of interactions of petroleum with particulates in waters and sediments.

### 3.1.3.3 Biological Fates

Microbial degradation is a major mechanism for elimination of petroleum pollutants from the aerobic marine environment. The environmental constraints that influence the rate of biodegradation have been defined. Substantial progress has been made toward determining and accelerating the rate of biodegradation in various marine environments, but further refinement and standardization of methodology are required before reliable rate projections can be made.

Evidence to date indicates that uptake of hydrocarbons from food and/or water is a universal phenomenon in animals, with partitioning from water or from particles or sediments after desorption being the key process. The levels of specific compounds in different species or different tissues do not relate directly to exposure which is due to differences in partitioning and to metabolic factors. Metabolic transformation of hydrocarbons occurs to some degree in most groups of animals. Observed concentrations in tissues are dependent on their ability to metabolize various compounds as well as physical-chemical processes, and in many cases metabolic rates may balance uptake rates with little apparent bioaccumulation. Intermediary metabolites are found in many tissues and may be retained longer than parent compounds.

#### 3.1.3.4 Information Gaps

Information gaps exist in the following areas: (a) the fate of hydrocarbons in algae, (b) the metabolism of heterocyclic compounds and hydrocarbons of high molecular weight, and (c) distribution and fate of metabolites.

## 3.2 Ecological Effects of Hydrocarbons in the Aquatic Environment

### 3.2.1 State of Knowledge

#### 3.2.1.1 Introduction

The study of the ecological effects of hydrocarbons on aquatic organisms and their habitats has received considerable attention all over the world for the past two decades. The following is a very brief overview of the present state of knowledge. Many important advances are only briefly mentioned or are not mentioned at all; the intent has been to provide the reader with a general perspective on the effects of hydrocarbons on marine organisms. For a complete review, the reader is referred to the many excellent scientific reviews which have been published and, in particular, to the 1985 National Research Council report "Oil in the Sea: Inputs, Fates and Effects" and to "Oil in Freshwater: Chemistry, Biology, Countermeasure Technology".

Extensive documentation exists on a wide range of effects of hydrocarbons on aquatic organisms, from standard toxicity testing to histopathological analyses of tissue from exposed organisms. Observed responses range from acute lethality to barely measurable changes in some physiological functions (e.g. respiration rate). Most of the experiments have been conducted in controlled laboratory situations. However, when field data have been available they have tended to corroborate conclusions based on laboratory results. The toxicants used in most of these experiments have been crude oil, residual fuel oil or their water soluble fractions (WSF). In a few instances individual compounds, particularly benzenes, naphthalenes and polycyclic aromatic hydrocarbons (PAHs), have been used.

In general it has been shown that WSF preparations of coal liquefaction and shale oil products are more toxic than WSF's of crude oil. Because the suite of compounds found in petroleum products is similar to that found in other fossil fuel derivatives, such as shale oil, coal, coal tar and synfuel, similar types of effects may be expected from these products. The magnitude of the response may differ substantially due to differences in the relative concentrations of the toxic compound(s).

Generally, freshwater aquatic organisms seem to be as acutely sensitive to petroleum extracts as marine organisms. However, oil has chronic and sublethal effects on survival, growth, and body chemistry not predicted by acute toxicity tests, and chronic exposures are not unusual in freshwaters, particularly in winter.

### 3.2.1.2 Bacteria

The presence of hydrocarbons has been shown to elicit responses at all levels in the marine food web from bacteria to fish. Natural bacterial populations will utilize hydrocarbons, particularly saturated hydrocarbons, but only if adequate nutrients are present. Bacterial assimilation of more complex hydrocarbons does occur, but the rate of biodegradation decreases markedly with an increase in the complexity of hydrocarbon structure. Low molecular weight cycloalkanes and monoaromatic hydrocarbons actually exhibit considerable membrane toxicity while the degradation of some polycyclic aromatic hydrocarbons can result in the formation of potent carcinogens. Bacterial breakdown is also strongly dependent on temperature and is severely limited in arctic conditions.

Some recent work involving chronic exposures suggests that there may be a linkage between the sub-lethal stress of oil and the susceptibility of the fish to bacterial infection. An interesting field example of such a phenomenon occurred following a winter spill of heating fuel into Lake Winona, Minnesota, in 1979, in which the fish died from Columnaris infection the following spring (Fremling, Proc. 1981 Oil Spill Conf. pg. 419-421). However, it is extremely difficult (perhaps impossible) to prove this type of linkage rigorously from field observations or correlations, and sound experimental studies are required.

### 3.2.1.3 Phytoplankton

The presence of petroleum-derived hydrocarbons can elicit both positive and negative changes in the growth rate of marine phytoplankton in laboratory experiments. The relevance of this response to natural field populations has not been ascertained, due largely to the great natural variance in the concentration of phytoplankton in the marine environment. Following the "Kurdistan" spill no measurable effect was observed on gross primary production in the waters affected by the spill. But in the Baltic Sea, following the "Tsesis" spill, there was an increase in phytoplankton biomass. This increase may have been the result of decreased predation by herbivores rather than an increase in primary productivity.

### 3.2.1.4 Zooplankton

A wide range of effects has been observed on higher-level organisms. Zooplankton may ingest hydrocarbons directly from the water, as contaminated food or in the form of oil droplets. Some zooplankton species have suffered mortalities in the laboratory at concentrations which are realistic at the site of a spill. In addition, a wide range of deleterious sublethal effects, including lowered feeding and reproduction rates and dramatic changes in community structure, have been observed. There is a wide range in the type and magnitude of the response, depending both on the life stage of the organism and on the exposure time and concentration of the hydrocarbons.

### 3.2.1.5 Macrophytes

Although macrophytes occupy an important trophic niche both in the intertidal, subtidal and shallow coastal zones and in freshwater, little is known about how they are affected by hydrocarbons. Intertidal macrophytes are obviously potentially vulnerable to contamination as well as to physical (smothering) effects. The only observed effects of hydrocarbons on macrophytes have been the bleaching of tissues of subtidal plants and the loss of fronds or entire plants as a result of heavy loading with oil. This remains a little studied area.

### 3.2.1.6 Benthic Invertebrates

Benthic invertebrates living in the intertidal zone, which include commercially important shellfish species, are also highly susceptible to oiling. They are exposed not only to the toxic effects of various hydrocarbons but also to smothering by large quantities of material and to destruction of their habitat by the spilled material or subsequent clean-up activities. Very large mortalities of both intertidal and subtidal benthos have been observed following several major and minor oil spills which have impacted the coastal zone. Because benthic organisms are much less mobile than pelagic organisms their use as experimental animals in the field is simpler. In addition, numerous sublethal effects have been observed, ranging from alterations in respiration, growth, reproduction and behaviour to changes in calcification, molting, ion transport and enzyme function. The type and magnitude of the toxic response varies a great deal among genera and species, and within life stages of various species.

Cuttings from the use of oil-based drilling muds may have local adverse effects on benthic organisms as a result of slow release of hydrocarbons adsorbed to the surface of the mud particles. Of particular concern is the potential for both tainting and sublethal effects in such valuable invertebrates as lobsters and scallops. Several studies are ongoing or proposed which are designed to address this question.

### 3.2.1.7 Fish

Fish are subject to a wide range of toxic effects from hydrocarbons. They are directly affected by ingestion of particulate hydrocarbons and of contaminated prey and by the uptake of dissolved hydrocarbons through the gills. The survival and health of eggs and larval stages are also threatened by the presence of toxic hydrocarbons. Indirectly, fish are affected by changes in the ecosystem which support them including, for example, changes in the numbers and/or species of prey and destruction of habitat through oiling or as a result of clean-up activities.

Most studies of the effects of hydrocarbons on fish have been carried out in laboratories. There it is possible to control the numerous natural variables such as temperature, salinity and food abundance which will influence any observed effects of a potential toxicant. In general, fish appear to be more sensitive to short-term, acute exposures of hydrocarbons than invertebrates, although this sensitivity varies a great deal. Also, demersal fish may be more sensitive than pelagic species. Fish can metabolize hydrocarbons and can excrete both metabolites and the parent hydrocarbons.

Numerous sublethal effects have been observed including histological damage, physiological and metabolic perturbations and altered reproductive potential. In addition to these direct effects, stressed organisms have been shown to have increased energy requirements and vulnerability to disease.

Laboratory studies of the effects of hydrocarbons on fish eggs and larvae have shown that some stages of fish eggs and most stages of fish larvae are more vulnerable than adult fish. Also, developmental abnormalities in fish embryos can result from very low concentrations of oil, over surprisingly brief exposure periods. Extrapolation of such laboratory findings to the field is risky. For example, fish eggs may survive exposure to a toxicant and hatch but the resultant larvae may be deformed or their function impaired so that they are unlikely to survive. When fish eggs and larvae die they decompose and start to sink in a few hours, becoming indistinguishable from the general mass of particulate organic material present in the water column. Thus, despite the fact that no massive kill of fish eggs or larvae has been observed during or following a major oil spill, massive mortalities may have occurred. However, there are strong indications from several field studies (Argo Merchant oil spill, New York Bight studies) of direct impact on fish eggs and juveniles.

Massive fish kills have not been observed either during or following marine oil spills. Laboratory tests of avoidance behaviour are inconclusive. While there is a tendency for many species to avoid even low concentrations of hydrocarbons, some individuals of the same species show no attempt to avoid even lethal concentrations. Catches of fish tainted with hydrocarbons following an oil spill suggest that not all fish avoid hydrocarbon-contaminated waters or prey. Experiments with freshwater species have resulted in identification of some of the compounds associated with tainting.

There is concern that certain fish species, particularly benthic-dwelling ones, could suffer tainting or sublethal effects from the use of oil-based drilling muds. To date, however, this subject has not been studied to any significant degree.

### 3.2.1.8 Marine Mammals

There have been accounts of the deaths of marine mammals following a number of major oil spills, but these deaths may not always have occurred as a direct result of the oiling or ingestion of oil by the animals. Smooth-skinned marine mammals, such as many whale species, are apparently less susceptible to oiling than those with well developed pelages. Ingestion of oil while grooming the oiled pelage can lead to illness and death. Of the species observed, marine mammals do not tend to avoid oil-contaminated water. In ice-covered waters the problem is exacerbated since spilled oil tends to concentrate in breathing holes and ice leads which marine mammals normally frequent.

### 3.2.1.9 Communities and Ecosystems

Long-term studies of oil-impacted marine coastal areas indicate that substantial and long lasting effects can result from contamination with petroleum derived hydrocarbons. There is also increasing evidence that chronic, sublethal contamination in coastal areas may be having an impact on some parts of the ecosystem, with a potential for serious long-term effects.

It is not possible to state confidently whether or not offshore marine environments are similarly affected by either acute lethal or chronic sublethal contamination. At present we are not able to distinguish between natural variations in these systems and those resulting from anthropogenic perturbations.

### 3.2.2 Research Capability

At present, research scientists in this department working on the biological effects of hydrocarbons on marine organisms are making substantial contributions at an international level. These studies require a substantial analytical chemistry/biochemistry component which is dependent on sophisticated analytical instrumentation (e.g. GC/MS, SEM, HPLC, ultracentrifuge, etc.). A strong analytical chemistry capability exists in the Scotia-Fundy, Pacific and Central and Arctic regions.

In the past, DFO scientists have studied the microbiological degradation of hydrocarbons and have also investigated the mutagenicity of toxicants. A study is currently in progress to investigate the role of biodegradation in the weathering of oils in low energy, sandy sediments.

There is considerable expertise within DFO which could be devoted to studies of the effects of hydrocarbons on primary production but at present there are no such studies under way. A substantial program of studies is now in progress to investigate the effects of oil on fish (notably Atlantic salmon), as well as fish eggs, larvae and juveniles and intertidal benthos. On the east coast DFO scientists pioneered the investigations of mixed function oxidase (MFO) induction in marine organisms by hydrocarbons and are continuing work in that area.

In general, there exists within DFO the expertise to investigate any of the numerous problems regarding the effects of hydrocarbons on marine organisms. There also exists an excellent potential to respond to an urgent requirement for studies of biological effects of hydrocarbons on marine organisms, should such arise.

### 3.2.3 Research Needs

Studies of biological effects rely heavily on complex analytical methods in chemistry, biochemistry, physiology and histopathology. Scientists would benefit from a quality control and standards program which would allow them to randomly check the accuracy of these complex methods.

Many of the observed biological effects are species-specific and depend on environmental parameters which are also site specific. Arctic areas pose a special problem because of the markedly different fate of oil spilled in this environment. Currently there is a conspicuous absence of biological effects studies on the west coast of Canada and in the Arctic. Both lethal and sublethal responses of west coast and Arctic species to hydrocarbons need to be studied.

Many sublethal effects of hydrocarbons on aquatic organisms have been demonstrated yet the mechanism of the toxic response has not been determined. Changes in behavioural response have been shown to occur at low concentrations of hydrocarbons but few data are available, especially for higher organisms. There is also evidence that in areas of chronic pollution mutagenic and tumorigenic problems are occurring, the latter being an especially serious problem with synfuel, coal tar and shale oil pollution.

While the base of toxicological data describing pathological effects of oil on individual fish, particularly juveniles, is growing, there is no easy way to link the effects on individuals with effects on populations. There is a need for experiments in which sub-lethal responses are induced in fish for calibration against future contribution to catches. Juvenile Pacific salmon and herring seem to offer opportunities for the conduct of such experiments. For example, juvenile fish might be marked and treated with oil to induce a sub-lethal response and then released, along with similarly marked and sham-treated controls. After several years of recapture effort, it would be possible to evaluate the actual effect of the oil exposure of juveniles on the subsequent catch of adults. These data would allow models of population effects to be checked against real data, without the need for oiling any natural habitat. A similar experimental design could be applied to populations in freshwater lakes, where more intensive monitoring between treatment and attainment of catch size would be feasible.

There is a need to organize the existing and future information on fate and effects into a framework which will allow an assessment of the interaction of these effects and potential effects on the entire ecosystem. For example, increased MFO activity in fish has been shown to be an indicator of the presence of some toxicant; but does this create an advantage or disadvantage for the organism or population? Particularly in the case of chronic pollution, sublethal effects such as behavioural changes and increased maintenance energy requirements may have a long term effect on the local ecosystem. The potential for this type of impact and for the long term recovery of sites from oil spills requires further study.

Spills of hydrocarbons can have a direct effect on the marketability of fish, either because of tainting of fish tissue by hydrocarbons or because of consumer suspicion of tainting. Understanding the mechanism of tainting will permit decisions to be made regarding the regulation of fisheries in the aftermath of a spill and also will assist with decisions on cleanup and containment activities. A chemical test for tainting needs to be developed and incorporated with other tests for the quality of consumer fish products.

### 3.2.4 Problems in Meeting These Needs

At present, departmental studies of biological effects of hydrocarbons on marine organisms are well directed but are limited in number. This is a result of the expertise in this area residing with only a few scientists, so that the total program that is carried on at any one time is very restricted.

There are serious resource limitations, both personnel and financial, within DFO for supporting this research. Many of the present studies are funded by PERD because of inadequate A-base funding. Because there are not sufficient personnel within DFO to do the work a large portion of it is being done under contract. Also, studies rely heavily on complex analytical techniques requiring expensive equipment. Much of this equipment is old and needs to be updated but current funding levels are not adequate to meet this requirement.

One additional concern is that the majority of scientists in this field are of a similar age. While they are not about to retire in the immediate future there is a need to ensure that there is a continuing core of expertise through recruitment and development of younger scientists.

### 3.3 Monitoring

Within the Department's mandate, the rationale for monitoring hydrocarbons is multifaceted. Monitoring provides a means:

a) to address uncertainties concerning the effectiveness of mitigative or regulating measures;
b) to provide assurance that hypotheses or viewpoints are reasonably correct, and
c) to provide advance warning of unexpected perturbations to the natural system.

There are two basic approaches to monitoring pollutants in an ecosystem:

1) to measure the concentration of the pollutant, or
2) to analyse properties of the system or components of the system which are sensitive to the pollutant.

In this instance, the pollutants of concern are hydrocarbons.

#### 3.3.1 Chemical Monitoring

As explained in Section 3.1, natural and anthropogenic sources of hydrocarbons are usually very complex mixtures. Analytical chemists have developed numerous methods for the determination of hydrocarbons, either individually or as a mixture, in various environmental matrices, including water, sediments and organisms. Methods which are suitable for continuous monitoring of water, such as spectroscopic methods, measure properties of the hydrocarbon mixtures. This type of analysis assumes that the composition of the material being determined is similar to that of some reference material. These methods are usually employed in situations where the concentration of hydrocarbons is high, e.g. monitoring effluents from pollution sources or following the physical transport of spilled hydrocarbons. Other pollutants and naturally occurring chemicals can interfere with this type of analysis at the low concentrations normally found in marine and freshwater environments.

There also exists a wide range of chemical techniques for determining the concentration of specific types of hydrocarbons in environmental samples. These techniques are time consuming, employ complex analytical methods and require expensive instrumentation. Rigorous quality control is required to use these methods with confidence at the low levels of contaminants normally found in the environment. The resulting data are very useful in detecting unforeseen changes in environmental quality; however, the quantity and complexity of the data make the interpretation difficult.

All of the chemical techniques are applicable in both freshwater and marine environments with only minor modifications.

### 3.3.2 Biological Monitoring

There are a number of difficulties associated with the use of chemical methods to monitor hydrocarbons in the environment. The input of toxicants may vary with time and discrete interval sampling may easily miss major episodic inputs. Also, cause and effect relationships are not well understood regarding sub-lethal effects of hydrocarbons on organisms; therefore it is not possible to define a concentration level at which concern is warranted. In chronically polluted areas, such as heavily urbanized or industrialized estuaries and harbours, a wide range of pollutants is normally present and the cumulative effect of these pollutants is unknown. Because of these problems, there has been a great deal of research directed at developing biological effects monitoring methods. These methods are based on the detection of changes in organisms which are induced by the presence of a specific toxicant or group of toxicants.

A number of biological effects indicators have been investigated including:

- acute toxicity,
- biochemical effects,
- cellular and histopathology,
- physiological effects, and
- effects on community structure.

Many of the studies relating to biological effects monitoring have been conducted in marine environments. The methodologies are being transferred to freshwater systems but considerable research is still required.

#### 3.3.2.1 Biochemical Methods

Biochemical methods monitor certain biochemical processes which are likely to respond to the presence of a contaminant. The mixed function oxidase (MFO) system has been found to be particularly useful in this regard. This assay is sensitive to the presence of polycyclic aromatic hydrocarbons and chlorinated hydrocarbons and the response is concentration dependent. Other toxicants may also trigger a response from this enzyme system. There is potential to increase the specificity of the assay through the use of antibody techniques and multi-enzyme profiles. The assay requires further development to calibrate the cause-effect relationships. Also, a knowledge of "normal" parameters is essential to the interpretation of the assay. While these data are accumulating for many marine organisms there have been relatively fewer assays carried out for freshwater organisms.

#### 3.3.2.2 Cytology and Histopathology

Changes in sub-cellular, cellular and tissue structure occur when organisms are exposed to hydrocarbons, even at low concentrations. The interpretation of these changes is complicated since similar changes can occur as a result of starvation. Also the degree of change depends greatly on the reproductive condition of the organism.

### 3.3.2.3 Physiological Methods

Organisms which are stressed by the presence of a toxic chemical will have increased energy costs associated with feeding, respiration and excretion. The scope for growth of an organism, a measure of the physiological condition of an animal, is determined by the components of an energy balance equation. This approach has been successfully used in documenting the effects of pollution on mussels and will probably be equally effective for other sessile filter feeders but further research is required before it can be extended to other organisms.

### 3.3.2.4 Community Structure

Scientists have been and are still concerned that undetected sublethal effects of pollutants may create long-term ecosystem level effects. For benthic communities, techniques have been developed and are in common use which describe the effects of perturbations on community structure. Diversity indices are commonly used but are not as useful as multivariate statistical techniques in distinguishing changes. There is a need for more research to establish formal procedures for transforming and weighting data. The present focus of community structure analysis is the macrofaunal component although the meiofaunal and microfaunal community responses are more sensitive to disturbances. However, knowledge of these communities is not sufficient at present to evaluate the relevance of observed changes. Again, research is required to standardize approaches and obtain "normal" data sets against which "test" data can be compared.

### 3.3.3 General

Monitoring marine or freshwater ecosystems to detect the presence of a contaminant at a level of concern is not a simple undertaking. Chemical methods can be used to monitor the concentration of specific compounds or groups of compounds. However, our knowledge of cause and effect relationships for sub-lethal effects is not sufficient to define with any confidence the level of contaminantion which should cause concern. At present there is no way of determining how much of a chemically measured amount of hydrocarbons is biologically available. Similarly, biological effects monitoring can identify changes which indicate the presence of an unnatural perturbation but the method cannot identify the specific cause. No single biological measurement can adequately serve as an indicator of pollution. It is therefore essential that there be an integration of chemical and biological methods for the monitoring of ecosystems for potential impacts of pollutants. "Normal" data sets need to be developed for both marine and freshwater organisms and benthic communities and research into the interpretation and standardization of biological effects needs to continue.

### 3.3.4 Differences With Respect to Freshwater

The actual biological monitoring techniques used for freshwater environments and organisms are generally similar to those used in marine settings, except that the species involved are different. The chemical monitoring for oil or hydrocarbons is the same.

Biological approaches include acute lethality testing of oils and effluents, sub-lethal effects such as MFO enzyme induction and histopathology, defining associations between hydrocarbons and tumors and infectious diseases, and describing the relationship between hydrocarbons and fish quality (tainting, texture, etc.). Probably the MFO enzymes offer the most specificity through antibody techniques, multi-enzyme profiles, and identification of DNA adducts. For field use, however, many of the measurements of sub-lethal pathology depend on our ability to recognize changes in "normal" parameters (e.g. MFO enzymes) and few freshwater species have had their "normal" ranges defined, given the influence of variables like diet, sex, age, maturity, season, etc. It should be emphasized that reliable data can be as useful in showing that oil is not the cause of an effect as in showing that it is. Similar reasoning may apply to future offshore production sites.

Canadian waters receive inputs of PAHs and probably monoaromatic hydrocarbons (MAH) by LRTAP from sources outside Canada. Probably aquatic sediments that can be dated using radioisotope techniques offer the best way to monitor the PAHs being imported to aquatic systems, with large volume water samples for the MAHs. The external sources seem likely to include transport northward from the USA (as seems to be the case with toxaphene), transport over the Arctic Ocean from the USSR and transport to eastern Canada from the northeastern United States and southern Ontario. Some remote headwater lakes in the Arctic and eastern Canada (and some suitable marine locations) should be selected for an effort to partition the inputs of hydrocarbons (and other LRTAP materials) into aerial and oceanic vectors.

Some of these efforts might seem peripheral to short-term DFO interests but they will contribute to an understanding of the processes affecting fish and fish habitat and understanding must form the basis for management. These efforts (particularly relating to LRTAP) are also directly relevant to DFO's fish habitat management policy. It is also implied from the above that DFO capabilities for chemical measurements of hydrocarbons (and stable organochlorines, metals, etc.) and radioiostopes, and for studies of biological responses from sub-cellular to ecosystem levels, should be nurtured rather than continue to be compromised.

# CHAPTER 4

# RELEVANT EARP RECOMMENDATIONS

## 4.0 Introduction

A review of recommendations made to government by a series of different environmental assessment panels indicates that relatively few have been specific to hydrocarbon pollution research. Most of the reports submitted by panels have contained comments on the inadequacy of scientific knowledge relating to possible impacts on the environment. However, recommendations have given greater emphasis to contingency planning and to measures designed to minimize the amount of waste materials entering the aquatic environment.

In earlier panel reports, the recommendations tended to be fewer in number and more general in content. Some recent panels, however, have submitted rather extensive lists of recommendations, some of which are fairly specific in nature. Although these panel reviews took place over a period of some eight years, it is of note that little of the proposed development activity which was of initial concern has actually taken place. Unfortunately it is also true that only a certain amount of the recommended research has actually been carried out. As a result we would still be unable to assess certain of the environmental concerns at such time that a given development went ahead.

## 4.1 Review of Recommendations

The following are panel recommendations relevant to the present study, with some comments on their implications:

### (1) Eastern Arctic Offshore Drilling - South Davis Strait Project (1978)

Only one recommendation is relevant, urging that "existing consultative mechanisms be utilized to determine the extent of further environmental studies". Specific areas of study identified were the movement and fate of oil in the area (including the fate under ice) and the potential effects of spilt oil on both Arctic cod populations and under-ice biota.

### (2) Lancaster Sound Drilling (1979)

The Lancaster Sound Panel recommended "a major expansion of government science programs in the North in areas where development is proposed." Among the specific areas of research identified were (a) the sublethal ecosystems effects of a blowout and (b) the basic mechanisms which lead to the high productivity levels found in Lancaster Sound. The panel commented that a lack of basic scientific knowledge was evident throughout the hearings and that present federal marine ecosystems research programs are not commensurate with the need.

### (3) Arctic Pilot Project (Northern Component) (1980)

This project concerned the transportation of liquefied natural gas (LNG) from the Arctic to southern locations. A major concern of the panel was the need for more information on the marine mammal populations of the area and particularly on the effects of underwater noise from ship engines and ice-breaking activity on whales and seals. The panel noted the lack of environmental knowledge necessary for the prediction of impacts and recommended a long-term research program which would give priority to imminent development schemes.

(4) Venture Development Project (1983)

The panel for this gas development project concluded that 'the most significant environmental impact of a blowout would be on juvenile fish' and that 'immediate disruption to fisheries in the event of a blowout or pipeline failure was more likely to arise from tainting than from fish kills'. They noted that 'studies are required on the concentrations of condensate and the time involved in tainting of seafish and shellfish'.

(5) Beaufort Sea Hydrocarbon Production and Transportation (1984)

A major concern of the Beaufort Sea Panel was the possible effect of vessel activity (including underwater noise) on marine mammals. The panel also recommended that DFO, as part of an Arctic coastal and estuarine fisheries research and management programn, identify and study fish habitats within the Beaufort Sea coastal area, and fish species which could be sensitive to oil and gas production and transportation, to develop effective monitoring and mitigation programs'. The panel further recommended that, prior to production and transportation of hydrocarbons from the Beaufort Sea region, DIAND, in consultation with DOE, DFO, the territorial governments and the proponents, prepare an integrated regional hazardous and toxic chemical management strategy for the handling, transport, storage, use and disposal of hazardous and toxic substances.

The development of both a strategy for the management of toxic chemicals and specific programs for mitigation necessitates the conduct of research in order to assess the level of risk and the extent of effects on marine organisms. In recognition of this need, the panel recommended that the Government of Canada make a commitment to a fifteen-year program of accelerated Arctic research' for which it identified six key elements, including funding for NOGAP. In addition, the panel recommended continued research on the behaviour, detection, and effects of oil spills in Arctic marine and freshwater environments.

(6) Hibernia Development Project (1985)

The Hibernia panel concluded that the major impact resulting from an oil spill would be disruption of fishing activity rather than effects on fish stocks. Consequently, the panel did not recommend further research studies; rather, it recommended that the proponent develop a monitoring plan which 'would take into account the viewpoints of responsible government agencies and allow for publication of results'.

(7) West Coast Offshore Hydrocarbon Exploration (1986)

The West Coast Offshore Panel report contained recommendations on research directed specifically towards DFO, for example:

(a) that DFO conduct research to determine the lethal and sublethal effects of naturally and artificially dispersed crude oil on critical life stages of migrating salmonid species,

(b) that DFO, in cooperation with other agencies, develop a comprehensive research program designed to reduce data gaps necessary to develop a credible model of the impact of an oil blowout on important fish species at their various life stages, and,

(c) that, in the event of a blowout, DFO be prepared to initiate a major research and monitoring program to gather information on the actual concentrations of dispersed oil in the water column and the lethal and sublethal effects on important West Coast species, particularly salmon and herring, at critical life stages, in order to assess more accurately the effects of oil on these species.

These recommendations reflect a concern that current knowledge of the effects of hydrocarbons on fish is inadequate, in particular for those species endemic to the West Coast. The recommendations indicate a special concern for the effects of a major spill because of the potential damage to distinct populations. To respond effectively to these recommendations could be very costly and it is, therefore, logical that care should be taken to establish priorities and to develop a strategy which would address the major areas of concern within a reasonable period of time. The third recommendation also deserves attention because, if DFO is to initiate opportunistic research in the event of a spill, there must exist both a certain level of scientific capability and a high degree of preparedness.

One other recommendation deserves attention. This urges that: 'before exploratory drilling begins, DFO develop a contingency plan for managing the commercial fishery after a blowout, including monitoring of fish for tainting and administration of closures'. This reflects a concern for tainting, an issue which has received increasing attention at recent panel hearings, particularly in those areas where there is an active commercial fishery.

## 4.2 Discussion

Of some note is the difference in emphasis between recommendations from east coast panels and those from the West & North. This, in part, reflects differences in behaviour of the respective water masses. Scientists generally agree that the long-term effects from development, or a major spill, in more distant offshore areas such as the Grand Banks may not be distinguishable from natural variations. The major concern is for spills which originate or move into shallow, nearshore and coastal areas where benthos is affected and eggs and juveniles of fish are frequently found or for spills in ice-covered waters where oil concentrates in leads.

The foregoing review of environmental assessment panel recommendations has concentrated on those which urged action on specific areas of research. A greater number of recommendations have emphasized preventative measures and controls, both for routine discharges and for episodic events. DFO's contribution to public hearings has been hampered on several occasions by its own inability to predict effects with any level of accuracy. This not only results from an insufficient knowledge of the effects of hydrocarbons on different fish species and different life stages but also from an inadequate knowledge of the distribution and behaviour of these fish. The high variability in these latter areas is also a major factor. Preventative measures and controls need to be such that they provide adequate protection to marine biota without imposing an unnecessary burden on the operator. In order to achieve this, a good understanding of effects is necessary. One particular, but somewhat different, aspect of this is tainting, which may not adversely affect the fish per se but which carries with it serious implications for their marketability. In this case, a knowledge of those hydrocarbon concentrations or specific compounds which may cause tainting in different species is clearly desirable.

Environmental assessment panels have recognized that a good knowledge of potentially affected resources and their sensitivities is important in order to ensure an effective response to a large spill. On such occasions priority areas must be designated as a prerequisite for protective action. After a spill, a measurement of damage is necessary in order to determine both the extent of compensation and the nature of possible restorative action.

The concerns raised by panels have been in direct response to specific proposals for oil and gas exploration and exploitation. However, many recommendations and many research needs are equally applicable to marine transportation, particularly oil spills originating from ships, and to other industrial activities in the marine environment, such as port developments. Despite the fact that the majority of the proposals before these panels have not yet come to fruition, the need for this knowledge is in no way diminished. In fact, what is clear is that a window of opportunity exists in which to address outstanding knowledge gaps in order to ensure more effective management at such time that the projects do go ahead.

# CHAPTER 5

# CLIENT INTERVIEWS

## 5.0 Introduction

A series of interviews was conducted with external clients in order to obtain an alternative perspective on research issues and priorities. Emphasis was placed on the major agencies to whom DFO provides information, advice and operational specifications and with whom DFO shares research programs and results. Selected contacts were made with representatives of the petroleum industry. It was intended to contact selected individuals in the academic community but for various reasons this was never achieved. A list of the people contacted is given in Appendix A.

The responses to the questions asked varied widely in their perspective and depth of detail, which is not surprising, given the differing levels of involvement and knowledge of the scientific issues. Copies of the written responses, along with summaries of the telephone interviews, are provided in Appendix B. In the following sections an attempt has been made to identify the major points made in response to each of the questions and to summarize the major concerns and issues identified by respondents.

Some of the observations made by respondents fall outside the specific area of hydrocarbon pollution. Several of these are identified separately as issues which may well be of direct interest to departmental managers.

## 5.1 Principal Research Needs

Certain research topics were identified by several respondents and are therefore noted as areas of more widespread concern or interest. Fish tainting was an issue identified as deserving special attention because of the potentially serious effects of tainting or perceived tainting in the market-place. Scallops, lobsters and quahogs were noted as particularly vulnerable species.

More research is needed on the sublethal effects of hydrocarbons on various components of the ecosystem and particularly on young life stages of important species. Of very real concern are the effects of chronic hydrocarbon pollution on these life stages. While the value of recent research on mixed function oxidase effects was noted by several, the relation of such effects to disease resistance and reduced fecundity were considered to be important areas to pursue.

Other frequently noted topics were the effects of hydrocarbon derivatives and breakdown products and the effects of dispersants, notably the difference in effect between dispersed oil and non-dispersed oil. One other item noted more than once was that of research on fingerprinting, the ability to trace hydrocarbons in tissues to their source. This latter is recognized as being primarily a DOE responsibility but one in which DFO has a definite role to play.

## 5.2 Responses to Specific Questions

**(A) IN YOUR VIEW, WHAT ARE THE OUTSTANDING SCIENTIFIC ISSUES RELATING TO HYDROCARBON POLLUTION IN THE AQUATIC ENVIRONMENT, BOTH MARINE AND FRESHWATER?**

The major issues are summarized as being the following:

(i) Tainting, both the hydrocarbon concentrations in fish and in the water column which cause tainting, and the persistence of tainting once established.

(ii) The effects of hydrocarbon pollution on critical life stages of important fish species and ecosystem components. A particular area of attention should be critical life stages of Pacific salmon and possible effects on chemoreception and schooling behaviour.

(iii) The effects of hydrocarbon derivatives such as nitrogen-containing hydrocarbons and degradation products.

(iv) The effects of chronic contamination on MFO induction and its correlation with decreases in fecundity and disease resistance.

(v) Toxicity studies on lobsters and scallops.

(vi) Continued development of analytical methods and chemical standards for specific hydrocarbons in water, sediments and biota, along with methods for monitoring effects in various aquatic environments.

**(B) IN YOUR VIEW, WHAT IS OR SHOULD BE THE ROLE OF DFO IN THIS FIELD, RESPECTING BOTH RESEARCH AND EFFECTS MONITORING?**

DFO was seen as having the major responsibility for research and effects monitoring in the following areas:

(i) Basic research on resource species, especially on eggs and larvae.

(ii) Studies of the fate/transport of hydrocarbons in the aquatic environment.

(iii) Long term ecological monitoring.

(iv) Assessment of the effects of chronic contamination on marine ecosystems and of bioaccumulation.

(v) Tainting of fish and shellfish.

(vi) Development of exposure/response curves for sensitive and indicator organisms.

(vii) Development of methods for effects monitoring and the design of monitoring programs to be conducted by industry.

**(C) TO WHAT ISSUES SHOULD DFO DEVOTE PARTICULAR ATTENTION, BOTH REGIONALLY AND NATIONALLY? ARE THERE ISSUES THAT YOU FEEL DFO IS NEGLECTING? ARE THERE ISSUES TOWARDS WHICH DFO MAY BE DEVOTING TOO MUCH EFFORT?**

The major issues identified on a national level were the following:

(i) Fish tainting

(ii) Impact prediction

(iii) Fate and effects of spilled oil

(iv) Effects monitoring

(v) Criteria for fish and fish habitat protection/sensitive area mapping

Regionally, the major areas identified were:

(i) Georges Bank -- understanding the system

(ii) West Coast, with emphasis on salmon, larvae and eggs and the native fisheries.

(iii) Beaufort Sea

No one identified an area where DFO was devoting too much effort.

**(D) DO YOU HAVE PARTICULAR PROJECTS THAT YOU WOULD RECOMMEND AS DESERVING DFO ATTENTION? AND WHY?**

This question did not elicit any suggestions not previously identified. Where there were specific replies given, the following issues were particularly noted:

(i) Tainting, with particular reference to scallops, quahogs and lobsters on Georges Bank

(ii) Sensitivity mapping

(iii) Studies on the effects of dispersant use.

**(E) WHAT MEASURES SHOULD DFO BE TAKING TO ENSURE THAT ITS RESEARCH RESULTS ARE MADE AVAILABLE AND RELEVANT TO ITS CLIENTS AND USERS? ARE YOU RECEIVING ADEQUATE SERVICE FROM DFO?**

Although respondents did identify one or two areas where good working relationships exist between clients and DFO research staff, the majority expressed a significant level of dissatisfaction with the department in this area. More than one noted that communication between DFO regions is poor and most felt that communication with clients on research plans, ongoing research and research results left much to be desired.

Among suggestions for approaches to improve the situation were the following:

(i) More consultation with clients during planning and project development.

(ii) Establishment of information "windows" to research institutes. (BIO was cited as having a good record in this area.)

(iii) More joint projects.

(iv) More workshops on specific topic areas.

(v) Publication of a research bibliography on a regular basis.

In general, DFO was perceived as not being responsive to client needs, although some respondents seemed reasonably satisfied with the current research effort.

**(F) IN LIGHT OF TODAY'S FISCAL CLIMATE, DO YOU HAVE ANY SUGGESTIONS WHICH WOULD ASSIST DFO IN DEVELOPING A LONG TERM RESEARCH AND MONITORING STRATEGY?**

Several respondents emphasized that DFO needs to maintain, and preferably increase, its level of effort in hydrocarbon research. Concern was expressed with respect to the possible impact of CODES on regional needs and problems. It was recognized that increasing attention will have to be paid to the potential effects of offshore hydrocarbon production on marine ecosystems.

Suggestions for the future centred on increased cooperation and coordination, both with external client groups and other government agencies. In the latter area, monitoring was identified as being a topic where more cooperative planning would be worthwhile.

**(G) ARE THERE ANY OTHER COMMENTS OR SUGGESTIONS THAT YOU WOULD LIKE TO MAKE RELEVANT TO THE HYDROCARBON POLLUTION ISSUE?**

Several expressed the view that DFO places too much emphasis on research for fishery management and not enough on habitat and hydrocarbon research. Several also felt that the department reacted to perceived crises such as oil spills but did not devote enough effort to basic research studies on ecosystems and the impacts of hydrocarbon pollution on them.

## 5.3 Other Issues

Some issues were identified which were peripheral to the focus of the current study. However, they are worth noting here since they are relevant to the department's broader program effort:

(i) DFO's capability to track an oil spill--an important support function in an emergency.

(ii) The need for a good knowledge of fish stocks. Regulatory agencies are becoming increasingly sensitive to the potential for claims in the event of an accident. Good information on resources is considered an important facet of claims assessment.

(iii) The need for a good program of water column monitoring. Such a program would provide data with which to assess the effectiveness of pollution control programs, e.g. MARPOL Convention.

(iv) The effect of noise on marine mammals. This is an issue associated with oil and gas development and one to which DFO should be devoting more effort.

## 5.4 General Conclusions

In drawing some general conclusions from this series of interviews, it is necessary to recognize the wide range of perspectives among the respondents and their varying familiarity with the scientific issues. Some very good recommendations for ongoing and future research were provided, which will warrant further analysis. Overall, the major thrusts were towards increased efforts in both basic and applied research, with emphasis on sublethal and chronic effects and on critical life stages such as eggs and larvae.

Two specific areas were emphasized as in need of additional effort. One of these is fish tainting. Both regulators and industry have become more aware recently of the implications of tainting, or perceived tainting, on the sales of fish in the marketplace. They see the need for a better understanding of the causes of tainting and improved methods for establishing the presence of tainting. A second area is that of sensitivity mapping. This is seen as a necessary tool for the identification and resolution of potential resource conflicts and for the establishment of priorities in the event of an emergency.

One particular area for concern is the rather widespread dissatisfaction with DFO in the area of consultation and communication with respect to research planning and results. Several good suggestions were provided for improving the current situation. This area, probably more than any other, deserves special attention if DFO is to serve its clients effectively and to gain their confidence as a responsive and responsible organization. It is also worth noting that industry has, on several occasions, failed to advise the department concerning its research plans. Consequently, a move towards more cooperation in planning and implementation of programs, both with industry and other agencies, could lead to mutual improvements in both efficiency and effectiveness.

# CHAPTER 6

## ANALYSIS OF EXISTING PROGRAMS

### 6.1 Methodology

An important step in determining future program strategies is the assessment of current programs. Accordingly, an inventory of existing projects was developed (Appendix B).

A classification system was adopted to assist in the analysis of the programs. Specifically, they were classified as to:

Scientific Aspects

- chemistry of hydrocarbons
- analytical methods
- fate/environmental chemistry
- biological effects
- monitoring

Geographic Applicability

- freshwater
- marine waters
- general
- site specific

Source of Funding

- A-Base
- NOGAP
- PERD
- Other

With respect to the analysis of program resources, a number of limitations apply, including:

- Direct program resources only were included; support and overhead were not.
- The resource figures were developed in late 1986 and are "deemed" to be estimated resource levels for 1987/88. It was not possible at that time to get more accurate figures because many regions were in the process of reorganizing programs and resources as a result of to Science integration and downsizing. A comparison between the PY total developed here, corrected for 2.75 PYs in Quebec not reported, compares very well with PY data developed by the Toxicology and Contaminants Science Working Group.
- The actual classification rating of projects requires a degree of subjective judgement.

These limitations are not considered to be serious, provided that the analysis is restricted to general trends. However, major support such as ships could be even larger than program resources. Such items are highly variable from year to year and their inclusion would have required complex calculations.

## 6.2 Analysis

The inventory included projects from all regions except the Gulf region, which has no projects, and the Quebec region, which did not report any. In fact, an estimated 2.75 PYs of effort exists and the exclusion of Quebec data must be kept in mind. For 1987/88, the total direct program costs in DFO totalled $1,923K and 19.1 PYs which included $806K in Scotia/Fundy, $487K in Pacific, $403K in Central and Arctic and $227K in Newfoundland region. The funding can be broken down as $780K salary, $1,099K O&M and $44K Capital.

The most active region is Scotia/Fundy, which reflects the long history and interest in oil pollution studies in that region, beginning in 1970 at the direction of the Operation Oil Task Force. In general, the historical growth and size of the program in each region is a reflection of the specific hydrocarbon problems that have existed or occurred in that region, primarily, but not all, related to the shipping and oil and gas sectors.

### 6.2.1 National Issues and Perspectives

The total level of $1,923K funding represents a significant program in terms of overall cost and the range of topics studied. While many of the researchers across the regions do communicate, there has been no national coordination to date. Several issues beg attention.

Firstly, there should be national coordination, through either the Physical and Chemical Sciences Subcommittee or the Toxicology and Contaminants Science Working Group, in order to ensure maximum program effectiveness within a common national strategy. There should also be closer coordination with the Biological Sciences Program.

Secondly, out of the total program funding of $1,923K, $981K (or 51%) is A-Base funding while $942K (or 49%) is from external sources. The principle sources are PERD ($555K), which can be considered a continuing program, and NOGAP ($300K), which is a sunset program (3 year extension for 1988/89 to 1990/91 has not yet received Cabinet approval). The main concern here is that the DFO hydrocarbon program is vulnerable to the fluctuation (or termination) of external funds. This dependence is further compounded by the fact that external funds represent most of the total O&M. Only $172K out of a total $1,099K (or 16%) is A-Base.

Thirdly, there is clearly a clientele for the programs currently underway and undoubtedly other demands have gone unfunded. Notwithstanding these real needs, there remains the question of what is a balanced DFO toxic chemicals research program, that is, the appropriate size of the DFO hydrocarbon program relative to the effort expended on other contaminants. This issue cannot be answered in isolation and must be addressed within an overall DFO contaminants science strategy.

Fourthly, the two largest hydrocarbon programs, in Scotia-Fundy and Central and Arctic Regions, are integral parts of the Centres of Designated Expertise (CODES) on Marine Contaminants and Freshwater Fisheries Contaminants respectively. A clear statement on the overall role and functioning of CODES is needed in order to ensure an effective national hydrocarbon program. This should address the question of interregional relationships.

### 6.2.2 Scientific Aspects

With respect to the basic chemical properties of hydrocarbons, very little research is conducted by DFO (total of 1.27 PY and $92K). This is not surprising. Much of this type of information relating to crude oils is either well established, or can be provided by the industrial sector and other agencies. The principal area where some chemistry study is taking place relates to effluents from oil-sands development. However, information on the physical properties of individual hydrocarbons is essential to the development of good predictive models.

The level of activity in analytical methods is somewhat greater, at 1.6 PYs and $194K. The ability to conduct chemical analyses is basic and integral to most of the department's research into the fate and effects of hydrocarbons. Quite logically, some development of methods occurs as various methodologies are adapted to the particular nature of the regional problems under study. Method development is often based on expensive equipment, which is difficult to obtain during the current period of fiscal restraint. There is also a need to pay continuing attention to both quality assurance and quality control.

The majority of DFO's hydrocarbon research is focussed upon the fate of released hydrocarbons (6.78 PYs and $901K) and the effects of hydrocarbon contamination upon living aquatic resources and ecosystems (6.74 PYs and $583K). Fate research, often called environmental chemistry or biogeochemical processes, benefits particularly in 1987/88 from the NOGAP Beaufort Sea oceanography project. The project is funded at $1,434K this year, with one major objective being to understand natural hydrocarbon distributions as a basis for the prediction of fate and effects of oil spills and discharges from Beaufort Sea offshore hydrocarbon production. Only $392K of the total cost of this project is directly attributable to the hydrocarbon research program. More generally, DFO work on fate includes studies on oil spill trajectory modelling, biodegradation, experiments using marine mesocosms and the study of natural oil seeps (Scott Inlet on Baffin Island). Most of this work relates to petroleum hydrocarbons, but studies also involve PAHs from other sources in Hamilton Harbour, Ontario and Sydney Harbour, Nova Scotia.

With respect to the effects of hydrocarbon contamination on fish and fish habitat, the DFO program is focussed mostly upon the toxicity of petroleum hydrocarbons to specific organisms and/or the induction of tumors in specific fish species by polycyclic aromatic hydrocarbons. A small effort is devoted to other "hydrocarbon formulations" such as oil/dispersant mixtures and oil-based drilling muds. Modest effort is also expended on tainting studies. Almost no effort is presently devoted to the study of impacts at the population level, although one project in 1986/87, using a workshop process, did develop an ecosystem model for the Grand Bank and used it to identify the potential impacts of oil spills in cases where supporting toxicological evidence has not been firmly established. The potential role of ecosystem modelling was investigated and recommendations were made for the future use of modelling in environmental impact assessment. The present void of population level impact studies is not satisfactory since the significance and therefore acceptability (to DFO) of certain projected impacts cannot be determined. However, this gap is not particular to hydrocarbons but applies generally to all of DFO's contaminants research programs. There is a need for better approaches to both area-wide and cumulative impact assessment for contaminants in the marine environment. Finally, a number of DFO researchers in at least three regions are studying the induction of MFO enzyme activity by hydrocarbon contamination. This work will provide a basis for the design and implementation of monitoring programs.

The level of effort expended on hydrocarbon monitoring is low (2.72 PYs and $154K). The data base indicates that monitoring is undertaken in Newfoundland region, Quebec region and Central and Arctic region. However, programs in other regions such as Scotia/Fundy do provide baseline data on hydrocarbon levels in the offshore and continental shelf waters but not necessarily at a regular sampling level. In the Great Lakes work, tumors in fish are monitored in Hamilton Harbour where bottom sediments are heavily contaminated with PAHs. Similarly, histopathological data and toxicant concentrations will be measured in Sydney harbour. More generally, increased effort in DFO monitoring programs is not expected until oil production begins in established offshore fields. Towards that end, DFO effects monitoring programs for fish would benefit from a better definition of biochemical and histopathological indices. The routine measurement of MFO activity as a pollution stress indicator requires the development of a reliable and practical assay.

### 6.2.3 Geographic Applicability

Projects were analyzed as to whether they were oriented to the marine environment, freshwater or of generally applicability. Not surprisingly, 60% (by dollars) of budget is marine, 27% freshwater and 13% generally applicable. This is a reflection of the geographic location of the involved research institutes and the nature of regional problems. The bulk of hydrocarbon issues is related to offshore oil and gas development, shipping and marine terminals. Thus the budget for marine studies is roughly double that for freshwater studies. The freshwater activities relate primarily to contamination in the Great Lakes Basin and in Arctic freshwaters, such as the MacKenzie River.

About 13% of the budget was deemed to be of general applicability but the total is very subjective. In some cases projects which could be of some general applicability were rated instead as contributing to both freshwater and marine. Thus, the results here for the category of general applicability are not considered to be significant. The main conclusion is that the budget directed to the marine environment is double the budget for freshwater. However, it is not possible in this analysis to determine the degree of applicability of the results of the marine studies to freshwater issues and vice versa.

# CHAPTER 7

# REGIONAL PERSPECTIVES AND PRIORITIES

## 7.0 Introduction

This section summarizes the issues and priorities in each work region (Scotia-Fundy and Gulf Regions are combined into one review). This information is relevant to the development of regional strategies but it also contributes to a review of national needs, priorities and strategies. The regional perspectives also include a summary of the historical development of each regional program, thus providing insight into the rationale for the current status of the program.

## 7.1 Newfoundland Region

### 7.1.1. Past Programs and Achievements

During the mid-seventies the Region reacted to the confusion and concern about the effects of marine oil pollution and how it might impact fisheries by establishing a small research activity in the area. Both scientific and trans-scientific issues were the subject of attention and it was determined that the question of effects on fish of long-term low-level exposure to petroleum was an important subject area where no information was available. Accordingly, a small research and evaluation activity was formulated in order to obtain insight into problems posed by marine oil pollution in general and to elucidate concerns about effects on commercially important marine fish and invertebrates in particular. The research strategy included exploratory studies for promising biochemical and histopathological indicators which would be useful for assessing animal stress per se or adaptable for monitoring and assessment studies at petroleum development sites offshore. Included in the studies was an investigation of the general and high-profile concern about hydrocarbon carcinogenesis - both in relation to effects on fish and associated potential problem of contamination and tainting of seafood products.

Although there are many gaps in our knowledge of dose-response relationships, the Region has been able to develop a good overall appreciation of the sublethal effects of hydrocarbons on fish, including such commercially important species as flatfish, codfish, lobster, and capelin. We are also in a much better position to evaluate the relative significance of hydrocarbons as important sources of marine environmental carcinogens. In relation to monitoring, we provided the initial field trials demonstrating the potential for using the MFO enzyme response as a simple biochemical index for assessing contamination in the environment. Through further joint efforts with OSS (Scotia-Fundy Region) the technique was established as a powerful management tool for addressing hydrocarbon concerns offshore. In relation to major scientific contributions of international importance by the Department, it should also be noted that this index has now been applied to a large variety of monitoring and assessment studies worldwide, not only in relation to hydrocarbons but also other types of mixed organic contamination.

In addition to accomplishments in producing a body of work of direct importance for assessing the attendant problems of oil pollution in the

Region, it should also be stressed that an important spin-off, which can be applied to aquatic toxicological investigations in general, has been the development of a small core of expertise in the complex area of biochemical toxicology and histopathology. This has been facilitated through interaction with faculty in the Departments of Biology and Biochemistry at Memorial University.

### 7.1.2. Immediate Issues and Needs

Issues include those of immediate interest for the Region in relation to fisheries protection as well as the following general question (which can be equally applied to all contaminants): What level of hydrocarbons in the environment is safe for aquatic organisms? Of immediate concern for this Region in relation to fisheries interests and client needs are issues related to the tainting of fish products by petroleum hydrocarbons, the nature and extent of the effects zone for pelagic and benthic fish around petroleum development sites offshore, the adequacy of plans for an effective biological monitoring program, the use of oil-based drilling fluids, and the consequences of an uncontrolled blowout on specific larval populations or on amenities such as fishing gear and capelin spawning beaches.

### 7.1.3. Priorities for Research and Monitoring

Priorities for research and monitoring in relation to immediate issues and client needs include an evaluation of dose-response relationships for fin and shell-fish tainting, determination of the present levels and types of contaminating hydrocarbons in major commercial fish stocks, better definition of biochemical and histopathological indices for use in monitoring studies, further evaluation of the toxicological potential of oil-based drilling fluids, and production of better modelling concepts and techniques to address concerns about the special sensitivity of fish larvae to petroleum.

Long-term research priorities, as distinct from immediate fisheries concerns, are essentially the same for all pollutants - namely elucidation of those levels which may be generally deemed as safe for marine life. Principal areas of interest include investigations on degradation rates of hydrocarbons in freshwater and marine sediments, assessment of the bioavailability of sediment hydrocarbons in heavily contaminated rivers, harbours, and estuaries, and definition of the spectrum of toxicological effects which may be associated with various levels of hydrocarbons. Areas of major toxicological importance include elucidation of the levels required for the production of harmful histopathological effects, and whether the high levels of hydrocarbons (namely the polycyclic aromatic component) commonly found in many rivers, harbours and estuaries or at petroleum development and refinery sites, have potential for either causing cancer or reproductive impairment in aquatic organisms.

### 7.1.4. Program Strategies

Program strategies should essentially follow two broad areas of investigation. The first involves defining sources and levels of hydrocarbons in the environment and determining their ultimate fate through studies of various biogeochemical processes. This can be loosely defined as the "chemistry" component of hydrocarbon research and typically consists of investigating processes under laboratory and, to a lesser extent, field conditions, and carrying out chemical monitoring and assessment programs on waters, sediments and biota. Chemical baseline and trend monitoring studies can be expected to become a required activity in any region where large-scale hydrocarbon developments are occurring in the marine environment and are a focal point of concern for fisheries and environmental interests. Concerns can be related to direct effects on fish and other biota, the tainting and contamination of fish products, or effects on amenities.

The second major strategic area of research involves the assessment of biological effects, which may extend from investigations at the cellular level through to the population level. It is presently recognized (and covered to a degree in fisheries and environmental laws) that either the direct and immediate poisoning of fish or the production of conditions which could seriously impact fish health and eventually lead to death is, in the absence of just cause, unacceptable for most interests. Thus investigations for evidence of acute toxicity or serious impairment of fish health through the production of serious histopathological or growth and reproductive effects will continue to be of primary value for regulatory and management interests. Also, since sublethal effects are far removed from population level effects, elucidation of the more sensitive of these responses is quite important for the development of early warning indicators for monitoring and assessment studies. It should be stressed that, with the exception of possible impacts on confined populations in small lakes and streams or similar, it is generally recognized that any pollutant-mediated effects at the population level will likely have to be catastrophic in nature before becoming separable from natural fluctuations in population size. Thus it would be injudicious to have to establish proof or rely on evidence of effects on population size as the criterion of unacceptability for pollution.

A corollary of this is that emphasis on population level studies, where the goal would be to establish small changes in stock size and abundance, would not be expected to produce a useful understanding of potential toxicity problems in the environment. Consequently, the strategy for assessing toxicological effects must be to focus primarily on effects on the individual. However, there should be an ongoing strategy by the worldwide community to understand how serious the impairments of fish health may have to be, both in degree and kind, before being translated into population level impacts. Part of this strategy obviously involves the broad area of basic ecological studies on population structure and function.

### 7.1.5 Research Needs for the Davis Strait and Labrador Areas

#### 7.1.5.1. Hydrocarbons in Fish and Seals in the Arctic

There is a need to carry out a comprehensive survey on the levels of hydrocarbons, and specifically polycyclic aromatic hydrocarbons, in fish and seals in the Davis Strait/Labrador Sea area. Survey work on fish should include studies on economically or ecologically important species such as arctic cod, Greenland halibut, arctic char and sand lance. Recent observations on high levels of hydrocarbons in the blubber of seals in the Beaufort Sea (Engelhardt 1984) highlight the importance of obtaining baseline data for seal populations. There is a good possibility that the blubber of seals is a good concentrator/integrator of hydrocarbons and could be an important index for trend monitoring studies. Different pinnipeds possibly integrate hydrocarbon pollution conditions in different environments, e.g., harp seals feed on different species over wide areas of the "open sea", ringed seals feed on different species inshore and bearded seals principally feed on benthic invertebrates in shallow waters. Initially, information should be obtained on as many species as possible included ringed, bearded, harbour, grey, harp and hooded seals, with the option that a species such as harp or ringed seal would be more appropriate for regular trend monitoring.

It is important to obtain baseline data on seal and fish populations and embark on long-term trend monitoring studies in order to address any of a number of real or perceived concerns that may arise in relation to harmful biological effects, contamination of fish products by PAH, tainting, etc.

### 7.1.5.2 Effect of Hydrocarbon Fumes on Seals

At certain times of the year, such as during the congregation associated with whelping, small portions of harp or hooded seals could be subjected to oiling. Although insuffficient evidence is available to rigorously address dose-response relationships, laboratory studies indicate that fairly heavy oiling would have to occur in order to have deleterious effects on pinnipeds. Overall, it would seem that newborn pups, which have little thermoregulatory ability, will be much more sensitive to oiling. Consequently, it would be useful to have information on the level of oiling required to produce harmful effects on harp and hooded seal pups. It is likely, however, that no amount of oiling, harmful or otherwise, will presently be "acceptable". Also, in relation to real biological impacts, it would seem that under most circumstances only very small numbers of animals will be coated, thus resulting in population disturbances of little or no consequence.

Given the right (or wrong) conditions, it is hypothesized that a far greater hazard to harp and hooded seal pups could be the toxic fumes associated with large oil spills. Unlike coating, which is expected to be a hit and miss phenomenon in ice leads, fumes could be more pervasive, covering not only the fringes but a whole area of ice floes for several days. As noted by Engelhardt (1986), tests on rats, cats and dogs demonstrated that high levels of vapours can be fatal after several minutes of exposure, progressing from loss of coordination to convulsions and death. It is also likely that eye effects such as the conjunctivitis and corneal erosions noted in oiled seals, could be exacerbated by exposure over several days to toxic fumes. As well as having a direct effect on adults and pups, it is also likely that maternal behaviour could be seriously altered, impairing rearing. Due to the seemingly real possibility for population level impacts, it is recommended that studies be carried out on the effects of hydrocarbon vapours on harp seal pups. The information obtained could be easily modelled to ascertain any risks associated with different size spills under different wind conditions. The idea would be to expose animals to harmful but, to the degree attainable, recovery-level concentrations of vapours with extrapolations made accordingly. (It is recognized that the lethality endpoint would have optimum scientific rigour, but lethality experiments, however important for risk analysis, will likely be found objectionable by sundry groups).

It is also important to stress that the information obtained in experiments with harp seal pups will be generally applicable for assessing effects on seals in water - should large numbers be trapped in areas having high aerial concentrations of toxic fumes. Procurement of such information on the effects of fumes could be especially useful in the preparation of guidelines for tanker routing.

### 7.1.5.3 Sublethal Effects on Fish

Considerable research has been carried out documenting the acute, and to a certain extent, the short-term sub-acute effects of oil on arctic organisms. This has included studies on fish, molluscs, crustaceans, plankton and ice (epontic) algae. Overall effects on arctic/sub-arctic species have been shown to be similar to effects noted in studies on similar species from other regions - in essence, arctic species display no special sensitivity or resistance to oil toxicity. The topic of sublethal effects is much more difficult to assess since studies are generally lacking. Chronic toxicity studies are both difficult and expensive and require wide expertise in various aspects of toxicology and interpretation. Therefore, it is unreasonable to expect that great numbers and varieties of animals or plants should be subjected to comprehensive sublethal effects testing. However, if we are to answer questions concerning information on "proven" safe levels of hydrocarbons for fish, sublethal effects studies will have to be carried out. With the exception of a few studies on fish (and in the UK on bivalves), there is little information available on dose-response relationships for petroleum hydrocarbons. Thus, in order to provide a greater degree of confidence in risk assessment studies, it is imperative to have at least some "hard" information on "proven" safe/unsafe levels of hydrocarbons for marine biota. In relation to concerns related to effects on fish in the Davis Strait/Baffin Bay area, dose-response sub-chronic toxicity studies should be carried out on the effects of contaminated sediments on Greenland halibut. This would complement the studies on codfish (relevant for Arctic and polar cod) and the recently funded PERD studies on salmon (relevant for Arctic char). Such information (in the case of Greenland halibut) on a deep water, commercially important flatfish species will be of critical importance for either supporting or discounting concerns related to possible effects of hydrocarbons on a major fish stock in the area.

### 7.1.5.4 Zoobenthic Effects: Special Perspective for the Arctic

Although not aware whether this particular interest has been raised before, it would seem reasonable to suggest that, in the case of arctic and sub-arctic seas, arguments can be made for much greater attention being paid to zoobenthos which, compared with warmer regions, is so much more important than zooplankton in assimilating energy. Also, due to immigration and the "three dimensional" nature of zooplankton populations, even major impacts can be expected to be relatively transient. This contrasts with zoobenthos which are not only "undimensional" in distribution but are generally immobile. Thus, any heavily impacted zoobenthic communities will have replacement periods measured in years instead of hours or days (as for zooplankton).

In essence, much stronger arguments can be made for both detailing zoobenthic communities and having a better understanding of possible subtle effects of hydrocarbon pollution on such communities in the Baffin Bay/Davis Strait regions. What level of sediment hydrocarbons are harmful to tunicates, bryozoans, holothurians and anemones?

## 7.2 Scotia-Fundy and Gulf Regions Combined

### 7.2.1 Past Programs and Achievements

A major research effort on hydrocarbon pollution began in response to the grounding of the tanker ARROW in Chedabucto Bay in 1970. At that time, research into the detection and fate of spilled oil and its impact on fisheries was conducted in the Halifax Technology Laboratory, the Biological Laboratory at St. Andrew's, the Atlantic Oceanographic Laboratory and the Marine Ecology Laboratory. Since 1973, almost all of this type of research in the region has been conducted by BIO scientists. This has been in the form of oil spill response work, general research and provision of expert advice and emergency consultation on both national and international levels. When the Gulf Region was formed resources for environmental contaminant research were to be provided by scientists from Scotia-Fundy Region; therefore, the historical summary of activities involving the two regions will be combined.

DFO scientists have continued to provide expert advice to government agencies in the aftermath of major spills, such as those involving the ARROW, the IRVING WHALE, and the KURDISTAN and the Venture gas blow-out. In the case of the KURDISTAN spill in 1979, the Ministry of Transport relied extensively upon BIO scientists for information required for the preparation of resulting legal actions. The Ministry of Transport also supported studies in BIO for 2 years following this spill, to determine the origin, distribution and fate of petroleum-derived hydrocarbons over the Scotian Shelf. (Most of the results of these studies remain confidential and cannot be published until all legal actions pertaining to the spill are complete). Scientists have collaborated with, and contributed to, research programs by the Department of Environment, both as scientific authorities and as participants in oil spill research programs. For example, since 1976, DOE-EPS and DFO scientists have conducted research into the impact of oil on saltmarsh ecosystems. On-going advice has been tendered to EPS with respect to oil spill countermeasures programs. Most recently, sampling and impact advice was provided to EPS regarding oiling problems of fish on the west coast and oiling of a commercial clam-bed in the Bay of Fundy. The lobster fishery in Sydney Harbour, N.S., has been closed for several years due to the high level concentrations of polycyclic aromatic hydrocarbons detected in lobster tissue.

Research activities are concentrated in three areas - 1) baseline (i.e., background and current) contaminant concentrations, 2) fate and behaviour of hydrocarbons, and 3) impact assessment. Determining the "baseline" concentrations of petroleum-derived hydrocarbons in the marine environment has received a great deal of attention. Seasonal and spatial variations of hydrocarbon concentrations in seawater from Halifax to Bermuda were studied over a 5-year period. A ten-year study of changes in the concentration and distribution of fluorescing hydrocarbons in the Gulf of St. Lawrence has also been completed. This study included a detailed investigation in 1971 of the area where the barge IRVING WHALE sank the previous summer with her cargo of Bunker C. Detailed studies of background levels have also been conducted on the Grand Banks, the Labrador Shelf, Hudson Strait, Lancaster Sound and Baffin Bay. Over the past 5 years considerable effort has been directed at understanding the scope and significance of submarine seeps in the eastern Canadian Arctic.

The physical movement and behaviour of oil following a spill has been extensively studied since the ARROW spill. Significant progress has been made on the modelling of spill trajectories and the development of hardware to track slicks. In this respect, BIO scientists provided the first hindcast oil spill trajectory model for the KURDISTAN spill using real time oil sightings and a combination of real time and historical oceanographic data.

There are ongoing studies of the long-term fate of oil in water and its sedimentation. Research programs continue into the fate and weathering of the heavy oil spilled during the ARROW incident. While it is not too surprising that heavy oil residues persist for many years in low energy environments, a recent study has shown that some hydrocarbons from a Venture condensate may also persist in intertidal, sandy sediments for at least one year. Laboratory and field studies are continuing on the degradation of Venture condensate and Hibernia crude.

Studies of the effects of petroleum hydrocarbons on marine organisms have included effects on the photosynthetic rate of phytoplankton, behavioural responses of marine organisms, effects on 'scope for growth', mutagenic effects and induction of enzyme activity.

Most recently, a number of programs have developed which represent new research directions such as the investigation of the hydrocarbon assimilative capacity of an estuary, the study of hydrocarbon stress in juvenile fish and the effects of hydrocarbons on capelin eggs and larvae. These projects are jointly funded by PERD and DFO and involve scientists from the Newfoundland Region.

Major contributions have been made by many DFO scientists to international scientific groups concerned with marine oil pollution. One scientist, involved with an international pollution program (IOC/MAPMOPP) over a period of ten years, was responsible for the interpretation of results of studies sponsored by the committee and the publication of the final report. Scientists participated in the steering committee responsible for the publication of the 1975 National Research Council (NRC) report "Petroleum in the Marine Environment" and the 1985 NRC report "Oil in the Sea", both of which are reference documents providing detailed accounts of our existing knowledge of the input, fate and effects of oil in the sea. In the same way many scientists have had important involvements with various international committees. They have also participated in the Baffin Island Oil Spill project (BIOS), maintaining strong interactions with the Environmental Protection Service and serving on the Environmental Studies Revolving Fund Program Study Committees. They regularly serve on scientific organizing committees for international contaminant conferences and have organized two major international pollutant symposia held in Halifax, N.S. BIO laboratories regularly provide analytical training for Third World students and investigators (China, West Indies), and scientists provide expert advice to Third World nations on oil spill programs (Middle East, Indonesia, Latin America). Numerous students from Canadian universities have conducted their graduate research at BIO.

Our understanding of the spatial and seasonal variations in baseline concentrations of petroleum hydrocarbons in coastal and offshore eastern Canada and the Arctic is now adequate. Sublethal effects of oil on marine organisms is still an area of major interest and is the focus of much of the research effort in this region. As was noted earlier, hydrocarbon pollution research in the region has taken a new direction and is focusing on the potential impacts on the fishery of sublethal effects from both chronic and acute exposure to anthropogenic hydrocarbons. Research projects are under development to study the ecological importance of natural hydrocarbon seepages. In addition to direct DFO support, a large proportion of hydrocarbon research in the region is being financed by the Environmental Studies Research Fund, PERD and Department of Supply and Services Unsolicited Proposal fund.

7.2.2. Regional Issues and Priorities (not in order of priority)

(a) Long-range transport of PAHs - The input of PAHs into the ocean by atmospheric fallout of combustion products of fossil fuels may be substantial relative to other inputs. This is of particular importance in lakes and streams in the Region where the effects of acid rain are being documented. It is important to understand the magnitudes of the various fluxes so that the appropriateness of mitigative measures can be assessed.

(b) Sublethal effects on marine organisms - The effects of petroleum-derived hydrocarbons on marine organisms are complex. Much of this work is being done in warmer climates with warm water species and, as far as we know, is species specific. It may not be possible to extrapolate from these results to a cold water environment. Research must continued on the effects of hydrocarbons on local marine organisms and on the mechanism of the toxic response. Of particular interest are potential effects of hydrocarbons on scallops and lobsters on Georges Bank.

(c) Ecosystem approach through mesocosm studies and ecosystem modelling - To DFO, perhaps the ultimate question regarding an accidental spill or chronic discharge of hydrocarbons is: how will this affect the fishery? While it is useful and informative to conduct studies of specific processes and/or organisms, it is impossible to assess the relevance of the results of such studies in the real world without the 'scaling-up' of the experiment. Mesocosm studies should be conducted to study population and ecosystem level effects and to investigate exchanges at the air-water and sediment-water interfaces. State-of-the-art approaches to holistic ecosystem modelling can assist in coordinating experimental design and interpretation of results.

(d) Impact of localized pollution on local and regional fisheries resources - What is the impact of a chronic localized source of hydrocarbons in the marine environment (e.g., Sydney, Halifax and St. John harbours)? The effect of chronic inputs of a wide range of toxic chemicals into a confined ecosystem such as a harbour or inlet has been shown to have drastic sublethal effects on the local marine organisms. The long-range implications of these effects is unknown. Cause/effect relationships have to be determined in order to facilitate decisions regarding area-wide and cumulative impact assessment.

(e) Long-term fate and effect of oil in low energy coastal environments - Low energy coastal environments provide ideal sites for recreational activities and are often highly productive and support a local fishery. They are also important as nursery and feeding grounds for offshore fish stocks. These same areas are the ones most heavily impacted by a coastal or nearshore spill. The long-term impact of hydrocarbon pollution on such sites requires further study so that effective mitigative procedures can be developed.

(f) Coordination of biological, chemical and physical studies - Studies need to be integrated from the planning stages to the interpretation of the results. Environmental issues are too complex to permit biological, chemical or physical data and observations to be evaluated properly in isolation.

(g) Impacts of offshore petroleum hydrocarbon development - It takes several years to obtain and interpret results from experiments with natural systems. So, although activity in the exploration and development of offshore hydrocarbon reserves is currently at a very low level, research activity should not. This lull in activity should be taken as an opportunity to carefully study the potential impacts, both positive and negative, of such development.

(h) Biological monitoring tools for early detection of potential impacts - A means of early detection of potential biological impacts of marine pollution is required. At a recent workshop in Norway, the induction of the MFO enzyme system proved to be the most sensitive biological indicator of stress resulting from the presence of petroleum hydrocarbons. The field use of this assay as a standard for the early detection of potential impacts should be evaluated. Research should continue to identify and develop other potential effects monitoring methods.

(i) Maintenance of a response readiness for accidental spills - This is a recurring issue. Not only is there a requirement for pre-commitment of resources but also a "State-of-the-mind" readiness which can only be maintained by research activity on related matters.

(j) Review of regulated limits for hydrocarbon concentrations in sediments for disposal at sea - Fish habitat management staff have a perennial problem in responding to Ocean Dumping applications for sediments containing hydrocarbon concentrations far above the regulated limits. The cumulative effects of different pollutants is largely unknown. Are the regulated levels meaningful or is there some better approach to assessing the suitability of sediments for dumping at sea?

(k) Flux of hydrocarbons into the Gulf of St. Lawrence estuary - The effect of fluxes of hydrocarbons from the St. Lawrence River on the water quality in the Gulf needs to be determined. This is a major but important task which should be incorporated with investigations of the fluxes of other pollutants in the estuary. Such a project would require input from the Québec, Gulf and Scotia-Fundy regions.

## 7.3 Central and Arctic Region

### 7.3.1 Introduction

The Central and Arctic Region contains virtually all of Canada's production of conventional and "synthetic" oil and natural gas and much of Canada's refining capacity. A significant proportion of national coal reserves are also found within the Region. A network of pipelines delivers gaseous and liquid hydrocarbons for processing and use within the region and for sale in other national and international markets.

DFO responsibilities are not the same in all parts of the Central and Arctic Region. In the Northwest Territories and Arctic Ocean, the Region exercises the complete federal mandate. In the inland waters of Ontario and the prairie provinces, authority for day-to-day management of inland fisheries has been delegated to the provinces. However, the federal government retains responsibility for the conservation and protection of fish habitat, including contaminants. This responsibility is exercised primarily in the Great Lakes and some other waters forming international boundaries. Because there is a mixture of jurisdictions involved DFO is negotiating arrangements with provincial governments in order to clarify responsibilities. A general agreement has been signed with Alberta and completion of habitat sub-agreements are a priority with each of the provinces. The draft agreement between DFO and Ontario regarding habitat management includes a research section in which both Canada and Ontario agree to "support research to provide information and technology required to protect, rehabilitate and develop fish habitat". This research will include work on "determination of effects of environmental hazards on fish and habitat; development of population models responsive to habitat stress; studies in support of the Canada-U.S. Great Lakes Water Quality Program; quantitative habitat evaluation techniques; development of early warning indicators of habitat deterioration; habitat rehabilitation and development techniques; and socio-economic studies to determine habitat value".

Furthermore, under the "Habitat Inventory and Monitoring" section, both Canada and Ontario agree to "establish and monitor the effect on habitat and fisheries of environmental hazards, including the Long Range Transport of Atmospheric Pollutants, and to evaluate chemical contamination of fish and establish necessary controls or consumption advisories relating to sport and commercial fish species". It is not yet clear how to interpret the matter of chemical contamination generally, let alone a specific group of contaminants like hydrocarbons. Both Canada and Ontario have science roles in problems of chemical contamination of fish habitat, but it is not clear who should do what. This issue will be addressed during the first year of the new agreement. The agreement will provide a model for agreements with other provinces.

A new protocol amending the 1978 Canada/U.S.A. Great Lakes Water Quality Agreement was signed on November 18, 1987, which places considerably greater emphasis on the problem of persistent toxic contaminants than did the earlier Agreement. In particular, the agreement for the first time makes reference to Remedial Action Plans, Lakewide Management Plans, pollution from contaminated sediments, pollution from contaminated groundwater and subsurface sources, and airborne toxic substances, all in the context of chemical contaminants. The potential impact on the Physical/Chemical Sciences work activity in the Central and Arctic Region could necessitate an enhancement of the present level of effort and resources.

Within DFO the Central and Arctic Region has been identified as the Centre of Disciplinary Expertise (CODE) for freshwater contaminants and toxicology. While the complete responsibilities of the CODES have not been fully defined, they do imply a long-term research commitment and a leadership/coordination role within the department.

### 7.3.2. General Issues Related to Hydrocarbons

Fundamental to the issues mentioned below is the ability to identify and measure hydrocarbons and some of their metabolic by-products at realistic concentrations in biological tissues and environmental samples, and to ensure that the quality of the measurements is adequate. These measures offer the means to estimate exposure of the fish, exposure being an essential component for evaluating risk and documenting damage to fisheries. Hydrocarbon measurements also establish the time needed for fish and habitat to clear hydrocarbon pollutants following spills and discharges. It seems likely that future study will extend the chemical characterizations needed to include various heterocyclic compounds, particularly those containing nitrogen, sulfur or oxygen in one or more of the aromatic rings, and to compounds capable of forming free radicals.

Perhaps even more fundamental for DFO is the need to carry the studies beyond exposure and into measures and projections of biological damage. These efforts will probably continue to rely on measures like fish kills, enzyme induction, tumor frequencies, bile fluorescence, measures of bioenergetics and growth, histopathology, organ weights, linkage between oil-induced stress and infectious diseases and parasites, tainting of fishery products, and fouling of fishing gear. There seem to be two major needs in this area. The first is for means to diagnose injury that has been caused specifically by hydrocarbons rather than by some other cause; some of the polyclonal antibody and immunoblot work recently illustrated by Stegeman (Science 231, 1287-1289, 1986) with PCBs may have promise, and the metabolite profiles and DNA-adduct work now appearing also seem promising. The second major need is to establish the impact of hydrocarbons on fish at the population/ecosystem level. In the latter case, we need instances where it is possible to isolate unambiguously the effects of oil and distinguish them from other sources of population variation, and to calibrate them against both the exposure and the various measures of individual pathology. This can probably be done best with a contained population or at least an anadromous one with strong homing tendencies.

The problem of polycyclic aromatic hydrocarbon (PAH) pollution is quite complex toxicologically and chemically. In addition to pure hydrocarbons there are many compounds in which one carbon atom has been replaced by a different kind, generally sulfur, nitrogen or oxygen, and these materials (PASH, PANH, PAOH) are toxicologically different. Some workers think that the PANHs or other substituted PAHs represent a significant biological hazard because of the ease with which they form reactive free radicals.

PAHs are present in petroleum oils, but they have a number of other industrial and natural sources, the main ones being coke production (for making steel) and incomplete combustion of carbon-based fuels (forest fires, cigarettes). This means that PAH compounds are present at low levels almost everywhere and some degree of risk of PAH exposure seems inherent in living on the planet. Almost any data on PAHs can generate a tangle of arguments regarding sources and implications. Generally PAHs are not acutely toxic nor do parent PAH compounds seem to bioaccumulate beyond fish in food chains. However, their metabolites are only now beginning to receive study and it is still uncertain what their implications are. Consumers of fish, human and animal, must have an ability to cope with the PAHs taken in with the fish and this raises a number of questions regarding the biological cost to those consumers. PAHs, in common with some other materials like aflatoxins, interact with DNA to produce adducts which are bound covalently to DNA nucleotides, but the implications of this are still not clear because cells have a remarkable ability to repair damage to DNA. Research is needed to evaluate the balance between rates of adduct formation and rates of repair in order to begin evaluation of the risk associated with any observed frequency of adducts (see Science 226, 1183-184, 1984, for example).

### 7.3.3 Regional Issues

#### 7.3.3.1 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons occur in sediments throughout parts of the Niagara River/Western Lake Erie/Eastern Lake Ontario drainages, probably largely from local industrial sources (e.g. coke production). There is growing evidence that fish from some parts of this system have high tumor incidences and PAHs have a proven capacity to initiate tumors in animals. The arguments linking PAHs and tumors in the area are controversial (Mix, 1986, Mar. Environ. Res. 20, 1-141), and it is important to continue studies in the Great Lakes in order to resolve the question. Good experimental work, combined with continued epidemiological observations, will resolve the issue conclusively. Some generic questions which may be answerable through continued study will include:

- Is the PAH pollution getting better or worse?
- What are the sources of the PAHs?
- Do the PAHs in the sediments cause the tumors in the fish?
- What do tumors mean to the fish?
- Are PAHs harmful to fish in ways other than initiation of tumors?
- What do induced levels of enzymes (MFO) mean to the fish?
- How are PAH metabolites in bile to be interpreted?
- What do enhanced frequencies of DNA adducts mean to the fish?
- What can/should be done about the PAH contamination?

If some of these questions can be answered clearly in a few instances like the Niagara area or Hamilton harbour (or Puget Sound or Sydney harbour, etc.) it will help to interpret PAH pollution throughout Canada and the world.

### 7.3.3.2 LRTAP (Atmospheric) and LRTOP (Oceanic)

Fish and sediments from the most remote areas of Canada (Arctic freshwater and marine sites) contain measurable levels of PAHs. Several papers have been published over the last decade showing the transport of PAHs to the Arctic (Pt. Barrow, Spitsbergen, etc.) by air currents. Air and water samples also contain a number of low-boiling aromatic hydrocarbons and an array of organochlorines and other unidentified materials. An oceanic pathway has been shown to transport radionuclides to the Arctic and it could presumably transport other contaminants as well. It would probably be a mistake to undertake research on these issues with hydrocarbons independently of other materials also subject to LRTAP and LRTOP. Rather, a general thrust to understand the hemispheric movements of chemicals (in addition to acid-forming oxides) by LRTAP and LRTOP and their implications for aquatic organisms should be made and it should include a hydrocarbon component. Some questions regarding the hydrocarbons would be:

- Do these represent a geological "background" or pollution?
- What are the fluxes of PAHs into and out of the Arctic?
- What effects do these hydrocarbons have on fish and fish habitat?
- What do the hydrocarbons mean to the use of fish?
- Are the hydrocarbons a risk to marine mammals that eat fish and invertebrates?

### 7.3.3.3 Arctic Oil and Gas Activity

Growth in oil production from the Arctic is continuing. Recently, production at Norman Wells was expanded to make it the third largest producing field in Canada. The productive formation lies directly under the Mackenzie River and many of the wells are located on artificial islands built in the river. A new pipeline up the Mackenzie Valley carries the oil to refineries in Alberta, and the small refinery at Norman Wells continues to operate. Planning is under way to extend the pipeline northwards to the Mackenzie Delta to transport oil and gas from there to southern markets. Offshore Beaufort Sea production is anticipated from several formations but the timing will depend on economic and political factors.

Currently Dene people living in the lower Mackenzie River drainage have complained that fish have become unacceptable for consumption due to the appearance of small brown livers in burbot and watery muscle flesh in whitefish. Investigation of the basis for these complaints is under way in the region but preliminary results do not indicate hydrocarbons as a cause of the phenomenon.

The behaviour of oil spilled in a small coastal Arctic bay has been studied thoroughly for several years at Pond Inlet and annual reports are usually given at the AMOP (Arctic Marine Oilspill Program) workshop in Edmonton each spring. The field work is completed and a number of scientific publications have recently appeared (Arctic 40, Suppl. 1, 1987). Unfortunately, the program included very little work with fish and so the implications of oil for Arctic fish and marine mammals have still not been explored adequately. In principle, the responses of Arctic animals to hydrocarbons should be similar to the responses of temperate animals, but the exposure may be greater due to low energy inputs to the Arctic, with resulting persistence of hydrocarbons for longer periods than in temperate climates.

A number of questions remain:

- Are the complaints concerning the quality of Mackenzie River fish related to hydrocarbons?
- How persistent is oil in the Arctic?
- Are Arctic coastal whitefish or charr movements interrupted by oil?
- Does oil impair the ability of fish to move between freshwater and seawater?
- How extensive is natural seepage of oil throughout the Arctic?
- What are the implications of production activity (population increase, ship passage, other chemicals, etc.) for Arctic fish and marine mammals?

### 7.3.3.4 Oil Sands and Heavy Oils

Since these deposits are located in Alberta and Saskatchewan, the DFO role in the many questions associated with the operations remains to be interpreted, following the completion of habitat agreements with those provinces. The region has done some work on the chemistry and toxicity of effluent components from the two existing plants (Syncrude and Suncor) and is currently doing some analyses of Athabasca Delta sediments for polycyclic aromatic hydrocarbons. Plans have been announced for expansion of the Syncrude plant and the construction of a third one, as well as for the heavy oil upgrading project near the Saskatchewan border. One existing plant (Suncor) suffered a fire late in the winter of 1982 and excess effluent escaped into the Athabasca River under the ice and moved downstream, with the result that the winter whitefish fishery had to be closed due to tainting.

Some questions that will have to be addressed are:

- What is in the various effluents from these operations?
- Are these effluents acutely or chronically harmful to fish?
- Do the effluents behave differently under ice-cover than they do in open waters?
- How are these effluents to be regulated in summer and winter?

### 7.3.3.5 Spills

Spills of crude and refined petroleum products will be of considerable research interest if they occur in situations offering opportunistic testing of hypotheses. For example, it is not clear how far downstream the volatile components of petroleum can travel under winter ice. It seems unlikely that such a question will be answered experimentally. Consequently, spills offering opportunities to examine the movement of oils under stream/river ice and to test different models will be of continuing research value. Spills in freshwater will have to be cleaned up and this will bring up the question of dispersants and other actions which might be taken. Spills may also result in legal action under anti-pollution laws and possibly claims for compensation in civil courts and there will be a demand for scientific evidence and opinion on the nature and seriousness of any damage to fish and/or habitat. Given the example above, some questions which could be answered include the following:

- Is movement of oils adequately described by physical and hydrologic data?
- How does the composition of the oil change over time and distance?
- How does the toxicity change?
- How does the tendency to taint fish change?
- What ameliorative actions are least harmful to aquatic life and habitat?
- How is exposure (time, concentration, oil composition) related to fish quality (tainting) and what recovery periods are required?
- How should the quality of exposed fish be measured?

#### 7.3.3.6 "Natural" vs. Anthropogenic Hydrocarbons

The question of "natural" vs. anthropogenic sources comes up over and over, although it may make little difference to the fish. Petroleum hydrocarbons occur naturally through seepage from unexploited geologic reservoirs; indeed, the observation of oil seepage at Norman Wells was the first hint of the large reservoir of oil present there. Higher in the same watershed, the Athabasca River flows through the tar sand area of Alberta, and there is constant erosion of hydrocarbon-bearing strata. Work by Levy at BIO has identified several natural seepage areas in the Eastern Arctic, and work by Wong and co-workers has begun to define background hydrocarbon levels in the coastal Beaufort Sea and has suggested that the Mackenzie River may be a source of hydrocarbons. Recent work by Environment Canada has identified several alkanes and aromatic hydrocarbons in Mackenzie River suspended solids and DFO studies have reported some of these compounds in the fish. In particular, levels of low-boiling aromatic hydrocarbons seem to be higher in the fish of the lower Mackenzie River in late winter than in late summer, suggesting that the source is within the river. In addition to petroleum inputs, whether due to geology or to human actions, there is also the complication of biological synthesis of several types of hydrocarbons, namely alkanes, some PAHs (e.g., perylene) and recently, toluene.

The most significant source of PAHs is combustion of carbon-based fuels, especially wherever there is not enough oxygen available to support complete combustion. This has a natural component through forest and peat fires and an anthropogenic component through combustion of fossil fuels and wood. A report for the Ontario Ministry of the Environment (ARB-TDA-Report No. 58-79, Table IX) estimated that nearly half (8 160 kg) the total benzo(a) pyrene released in Ontario (17 930 kg) originated with forest fires. Almost all the other half (9 332 kg) came from coke production (Hamilton and Sault Ste. Marie). A study of PAHs in air samples at Barrow, Alaska, identified several PAHs which were attributed to mid-latitude combustion of fossil fuels (Daisey et al., Atmos. Environ., 15, 1353, 1981). Modern 'air-tight' wood stoves produce PAHs effectively.

The only way to address this problem will be through continued research on the sources and environmental behaviour of hydrocarbons. For example, synthesis of alkanes by freshwater algae seems worth more study since alkanes are the most abundant compounds in petroleum and since some of them are widely distributed in aquatic organisms. We often find materials which we suspect are alkanes (especially $C^{15}$, $C^{17}$, $C^{19}$, $C^{21}$) in freshwater fish, and we assume that these represent biogenic sources. Unfortunately, the presence of both natural and anthropogenic sources gives rise to the "My brother did it" syndrome in which a claim to damage from hydrocarbons can be countered with the argument that any injury may have been caused by those of natural origin rather than those from an emission source in the area.

#### 7.3.3.7 Coal and Coal Conversions

It is difficult to evaluate the implications for DFO of regional coal production. Certainly the potential for enormous production exists in the region, particularly in western Alberta and southern Saskatchewan. Coal is a source of PAHs and heterocyclic analogues of PAH, as well as of several metals. If coal should become more important in the future (which seems certain) due to political events such as those in South Africa or to shortages of other hydrocarbon fuels, then it may be opportune to begin study of coal now in order to be in a strong position at that time. In addition to production of coal, the region uses coal in thermal power production, in coking, and as domestic heating fuel, although this latter use is relatively small now. Coal combustion contributes PAHs (and acid-forming oxides of sulfur and nitrogen, and heavy metals) to the air, and the region receives LRTAP deposition from coal burning in both Canada and U.S.A.

## 7.4 Pacific Region

### 7.4.1 Background

In 1985, the landed value of Pacific Region commercial fisheries was about $350 million; the recreational fisheries were valued at about $170 million; the fishing fleet was composed of about 4,500 commercial and an estimated 133,000 recreational vessels; about 25,000 persons were employed in commercial fisheries; and over 300,000 persons held tidal waters sport fishing licences. The Pacific Region fishery is thus an important resource, nationally as well as regionally. The five species of Pacific salmon and the Pacific herring are the chief resources, but halibut, other groundfish and invertebrates contribute importantly. Fish farming is a relatively new venture in the Pacific Region but one which is receiving a rapidly increasing amount of attention and investment, as evidenced by the number of licences issued and pending.

The coastal shelf of the Pacific Region is relatively narrow, but the coastline itself is about 20,000 km in length, heavily indented by fiords, and characterized by many islands, sounds, channels and seaways. Although the five species of salmon spend a significant part of their life histories in oceanic waters, most of the commercial and recreational catches are taken within sight of land, often in sheltered seaways. The juvenile salmon migrate seaward from their natal rivers through nearshore areas, often for great distances before reaching open shelf waters. In the nearshore migration and rearing areas, numbers, biomass and ration requirements per unit area can be very high over extended periods of time. These aggregations may be persistent for much of the spring and summer period over great lengths of the coast, as juvenile salmon from diverse rivers of origin progress seaward. Spawning, hatching, and larval rearing of Pacific herring usually occur close to shorelines, often in or adjacent to the intertidal zone. These features of the biology of key resource species, the locations of harvests, coupled with the geography of the coast and the distribution of hydrocarbon threats, distinguish the Pacific from the "Atlantic" fishery regions of Canada. The species mix, biology, and geography of the Pacific Region are such that some of the generalizations about the vulnerability of Atlantic fisheries to hydrocarbon impacts should not be assumed to be applicable to west coast marine waters.

The management of freshwater fisheries in British Columbia has been assigned to the province. However, DFO retains the mandate to manage the freshwater spawning, rearing and migration habitats of the five species of Pacific salmon.

### 7.4.2 Brief Outline of Past Hydrocarbon Effects

The major past hydrocarbon efforts in the Pacific Region have been in the general field of impact assessment and management actions such as prosecutions. Although this work was not research per se, there was significant involvement of research staff and research methodology. The major efforts concerned proposals for increases in shipment of crude oil by supertankers, proposals for construction of major tanker terminals or the construction of crude oil pipe lines, and most recently, proposals to resume exploration for hydrocarbons in the waters of the north and central coasts of the Pacific Region. There has been heavy involvement of Ocean Sciences staff of the Pacific Region in Beaufort Sea environmental assessments and related science. Ocean Sciences has also developed spill tracking models and investigated PAH contamination. To a lesser extent, some research has been conducted on spills of opportunity and on effects of hydrocarbons on resource species.

The impact assessment work dictates some of the major research issues and examples are therefore listed below.

#### 1. Kitimat Pipeline and Tanker Terminal

Proposals for a major crude oil terminal, with a new pipeline from Kitimat, were the subject of a major Termpol assessment with considerable input from the Department. Key issues were the risk of major spills from crude carriers operating in confined coastal seaways and their approaches. Key resources considered were the salmonids, herring and groundfish.

#### 2. Comparative Oil Port Risk Analysis

This entailed a study of the relative risks to fisheries of crude oil spilled from large crude carriers en route to a number of postulated transhipment terminals on the West Coast. It included assessment of alternate routes to a number of the hypothetical terminals and risks of spills at the different terminals. Taken into account were navigational risks, ecosystem sensitivity, resource sensitivity, distribution of resource species, and season.

#### 3. Canada Shipping Act Part XX Amendments

Distributions of resource species, resource sensitivity, and shipping routes were used to assess fisheries risks due to hydrocarbon pollution from shipping in Canadian waters.

#### 4. Trans Mountain Pipe Line Co.

Trans Mountain proposed a new pipeline to serve U.S. "Northern Tier" refineries with Alaska and offshore crude to be delivered by supertanker to a proposed new terminal at or near Port Angeles, Washington. Competitors also proposed new terminals again at Kitimat, in northern Puget Sound, and at or near Skagway, Alaska. The Department conducted internal reviews of the relative risks to fisheries resources arising from the various proposals but did not take part in public assessments. However, Departmental staff were subpoenaed to give expert testimony on behalf of intervenors in the National Energy Board Hearings of the Trans Mountain application, which would have entailed construction of a new pipeline on Canadian lands, as well as increased tanker traffic in or near Canadian waters (Canadian economic zone, Juan de Fuca Strait). Major concerns were the effects of spilled crude on resource species. Testimony to the NEB attempted to take into account the fact that such forms as juvenile salmon are migratory and may be at risk in more than one geographical compartment.

### 5. West Coast Hydrocarbon Exploration Assessment

As part of a FEARO analysis of proposals for resumption of hydrocarbon exploration in waters north of Vancouver Island, DFO scientists made extensive contributions to the review of the IEE prepared by the proponents, to assessments of potential impacts on fisheries and to the formal Departmental position on the proposals. Again, the chief concerns were the impacts of spilled oil on the fisheries resource, chiefly salmon and herring, but not limited to them.

## 7.4.3 Continuing Concerns

### 1. Hydrocarbon Exploration

The moratorium on West Coast offshore exploration will soon be lifted, opening the door for exploratory drilling, possibly to be followed by delineation and production. Concerns about the effects of a worst case oil blowout remain. The distribution and biology of resource species is such that, in the worst case, extremely serious direct and indirect effects are possible.

### 2. Potential Spills from Crude Carriers

The Trans Mountain proposal for increased tanker shipments of crude to a Juan de Fuca Strait terminal was rejected by Washington State. However, there remains the regular shipment of Alaska and offshore crude to northern Puget Sound refineries, averaging several 100,000 ton tankers per week. The North Slope crude is shipped from Valdez, Alaska in tankers which transit Canada's West Coast at distances from shore decreasing southward from the Queen Charlotte Islands, with the final leg in Juan de Fuca Strait. Previous qualitative analyses suggest some risk to fisheries along the entire transit, increasing southward to southwestern Vancouver Island and Juan de Fuca Strait. The terminals and refineries also pose risks due to potential hydrocarbon spills.

### 3. Coastal Product Shipment

The small communities, pulp and paper mills, and other industrial activities (mines, logging camps etc.) along Canada's West Coast are served by small hydrocarbon product tankers. While the volumes of individual shipments are small, the number of shipments, the toxicity of the cargoes, and the location of the routes and delivery points with respect to resource distribution, particularly juvenile stages, provide cause for ongoing concern.

### 4. Pipelines, Terminals, Refineries, Marinas

Ongoing concerns about the potential for spills from such facilities exist, as for product shipments.

### 5. Chronic Discharges, Non-Point Source Pollution

Insofar as these are related to population distribution most of the concern focusses on urban centres, both on the coast and on interior rivers.

### 6. "Exotic" Hydrocarbons

Use, production, and shipment of "exotic" hydrocarbons is concentrated in the greater Vancouver area, although emissions from some industries, such as pulp mills in more remote areas, require a watching brief.

### 7. Long Range Transport of Atmospheric Pollutants

The Pacific Region is "downstream" from the Pacific Ocean, minimizing the LRTAP problem on the West Coast relative to that for Central and Eastern Canada. However, local problems from industrial point sources, large urban/industrial developments and from Washington State are possible, though largely speculative at this time. The only widely distributed source of atmospheric pollutants is the annual in situ burning of logging slash, with widespread outputs of wood smoke. Combustion of "hog fuel" and other wood products in mills is also a significant source of input to the atmosphere. Whether these are hydrocarbon problems of concern to fisheries is moot at the present time.

Locations of concern are the Central and North Coasts of British Columbia for hydrocarbon exploration; the West Coast of Vancouver Island, Juan de Fuca and Georgia Straits for tanker and refinery spills; greater Vancouver and the lower Fraser Valley for chronic discharges, non-point source effluents, "exotic" hydrocarbons, and LRTAP sources; virtually the entire coast for product shipment and handling; and urban/industrial centres, coastal (e.g. Kitimat) and interior pulp mills (e.g. Prince George area) as sources of exotic hydrocarbons.

## 7.4.4 Research Issues and Priorities

### 1. Toxicology

Most of the toxicological data used in the Pacific Region impact assessments to date has been acquired outside the Department and outside the Region, primarily from the U.S. Pacific Northwest and Alaska. The work has been motivated by the same major issues that concern Canadian West Coast management; hydrocarbon exploration, production, and shipment. Our reliance on research by others has been adequate for much of the impact assessment work and of course has been cost effective in that context. However, additional investigations using modern flow-through techniques on the sublethal effects of dissolved and particulate crude fractions on juveniles of salmon and herring are needed. In particular, the effects of dissolved, particulate, and dispersed oil on the biology of juveniles in stratified water columns require study. In vitro behavioural work suggesting that juveniles of resource species may avoid oil, requires extension to conditions in which other determinants of behaviour, such as light, depth, boundary, and salinity stratification can be included. Some work with other pollutants suggests that such factors as light, depth or salinity preferences may override avoidance behaviour, with deleterious effects for the fish. Further work is also required on the feeding and growth of resource species exposed to contaminated prey.

## 2. Hydrocarbon Impacts on Fisheries Yields

Even with markedly improved toxicological data, the estimation of hypothetical or actual effects of hydrocarbons on fisheries yields would remain problematical and controversial. Here, as elsewhere, modelling of fisheries production is advancing rapidly, subject to the limitations of stock assessment data. In particular, data on distributions, migrations, and sources of mortality of larval and juvenile forms are serious limitations. The system noise is such that the Region feels that in the event of even a major spill some form of modelling would be required to estimate effects, as opposed to direct estimation of losses. This is due in part to the inherent difficulty of observing the affected fish. Thus the testing and development of models for estimating spill impacts on stocks resulting from juvenile exposure is a priority. Data on the distribution, migrations, and biology of juveniles of resource species is improving and appears to support generalizations based on earlier data. However, no ready solution to the need for detailed and extensive "site specific" (this is a misnomer, as very large areas could be involved) data in the event of a real spill seems likely. Therefore, research and negotiation with industry on acceptable means of estimating spill impacts is essential as a basis for mitigation and compensation.

Large scale experiments to compare survival of treated and control fish to catch and escapement, using stocks from different types of areas, are required. Juvenile salmon and herring are priority subjects. Such experiments would require a long term commitment to the recapture phase and could be used to validate predictions based on toxicology and modelling. The results would still beg the question of the impacts of any particular spill, for which the numbers, species and stock composition etc. would be difficult to quantify. However, such research would be especially valuable for determining the extent to which various sublethal effects would be expressed or detected at the level of the population or stock. Similar experiments can be envisaged for assessing indirect impacts of oiling, such as ecosystem and food web effects. However, the latter experiments would require the contamination of significant areas of natural habitat, with the risk of serious effects on natural stocks or migrants, and the design for quantitative results would be more difficult. Nonetheless, because of the extensive migrations of juvenile salmon in nearshore areas, their diets while there, and the sensitivity of nearshore food webs to hydrocarbons, development of methodology relevant to indirect effects requires attention.

The above has been prompted by priority concerns for major hydrocarbon spills resulting from supertanker accidents and significant blowouts from exploratory wells. However, the same basic problems apply to concerns about the effects of smaller spills from product movements, whether from coastal shipping, processing, or transhipment facilities.

## 3. Chronic and Non-point Sources, LRTAP, etc.

Such sources of hydrocarbon pollution are generally felt to be more serious in the long run than the occasional short term large spills. This may be debatable in areas such as Canada's West Coast, where chronic low level pollution is likely to be lower than in areas affected by higher levels of population and industrialization and where long range transport of hydrocarbons is limited by geography. However, locally, in areas such as greater Vancouver, the lower Fraser Valley, and other sites where population and industry converge with significant fish habitat, increased research on chronic hydrocarbon inputs to water, biota, sediments, and atmosphere is needed. The results of such work would determine the need for additional Pacific Region toxicological and biological studies. However, exploratory research on the uptake and biological effects of such compounds as the PAHs on West Coast species is needed to define the potential for problems.

# CHAPTER 8

## CONCLUSIONS

DFO conducts a substantial program of research and monitoring into the fate and effects of hydrocarbons in the aquatic environment. This program has been built up over the past two decades in response to the needs of regulatory agencies and the oil and gas industry. Earlier results were targetted primarily to issues relating to offshore oil exploration and shipping. Present and future demands relate more to offshore production, synthetic fuels and sources of polynuclear aromatic hydrocarbons, including atmospheric transport.

The role and mandate of DFO Science with respect to hydrocarbon pollution includes the following:

- to conduct scientific research into the biogeochemical processes and the biological effects of hydrocarbon contamination, and the general dissemination of scientific results;

- to monitor the effects of hydrocarbon contamination and its distribution in the receiving environment (as distinct from, but not including, compliance monitoring) in order to assess the effectiveness of existing standards for operational discharges, to assess the effects of accidental spills and to determine regional trends;

- to provide fisheries and aquatic ecosystems advice to regulatory agencies and other clients, public or private, in the evaluation of industry proposals for hydrocarbon exploration, exploitation and transportation, in the design of systems and strategies for oily waste management, effects monitoring, R&D on cleanup equipment and techniques, and contingency planning;

- to provide scientific expertise and advice to on-scene commanders and others during oil spill emergencies, including the conduct of supporting scientific and logistic field activities, where appropriate;

- to provide expert witnesses and information in litigation concerning liability and compensation in relation to oil spills;

- to provide scientific expertise and advice to other research programs as it relates to the review and implementation of proposals for hydrocarbon research. This role may include occasional responsibilities as scientific authority on relevant contracted studies; and,

- to contribute to international efforts to understand and control hydrocarbon pollution.

The 1987/88 program level, excluding support/overhead, was approximately 19 PYs and $1.9 million, spread across most DFO regions, except for the Gulf Region. Although the program activity lacks effective national coordination, and while an improved level of consultation with clients is desirable, nevertheless, the current program appears to be directed towards appropriate priority topics. However, a more systematic and coordinated periodic review of priorities on a national basis is warranted in order to ensure maximum program effectiveness.

Relatively speaking, the effort on hydrocarbon issues is an extremely small proportion (about 1%) of the total Science sector budget. It also represents about 19% of the Science effort on contaminants (excluding LRTAP) which is roughly commensurate with the priority of hydrocarbon issues relative to problems posed by other contaminants (as concluded by the DFO Toxicology and Contaminants Science Working Group). While the contaminants budget as a whole is probably not adequate to meet client demands, the current proportion of that effort devoted to hydrocarbons is a reasonable level. The future budgetary level devoted to hydrocarbons will depend upon new DFO strategies being developed now to address a variety of toxic chemical issues and priorities.

A serious shortcoming of the present funding base is that 49% of the total dollars comes from external funding. This funding is biased towards O&M, in that only 16% of the O&M is A-Based. Thus the long term base for the program is not very stable. However, given the climate of fiscal restraint, DFO programs will continue to access external funding sources, provided that proposals are consistent with DFO priorities. Moreover, the program suffers from the same malady afflicting the contaminants program as a whole, namely, old and in many cases outdated sampling and analytical equipment.

Based upon consultations with DFO clients in industry and other government agencies, the key hydrocarbon research, monitoring and information analysis priorities at this time include:

(a) determination of the sub-lethal effects of petroleum hydrocarbons on fish and marine mammals, with emphasis on sensitive life stages such as eggs, larvae and juveniles;

(b) research and modelling into population and ecosystems level effects is encouraged but an overall strategy for studying systems effects is needed and should be generated as part of the toxicology and contaminants science strategy; the long term goal should be to attain a capability to conduct impact assessment at the population and ecosystem levels and to predict cumulative and long term effects;

(c) development and application of techniques for determining stress on aquatic organisms and relating these to the incidence of specific contaminants, with particular reference to developing systems for early warning and for effects monitoring;

(d) maintenance of a regional capability to respond immediately with scientific support and the provision of assistance and advice to an on-scene commander, in the event of a spill of hydrocarbons; where this capability does not currently exist, arrangements should be made with an adjacent region to ensure a satisfactory level of DFO response;

(e) acquisition of a better understanding of the mechanisms of fish tainting by hydrocarbons so that both field tests and mitigative measures can be developed;

(f) development of an improved understanding of the rates and modes of oil degradation in low energy environments, including the Arctic, and examination of ways in which degradation can be enhanced, as a potential cleanup technique;

(g) improved understanding of the sources and rates of hydrocarbon introduction to the aquatic environment via atmospheric deposition, including arctic waters;

(h) development of the capability to identify and assess the impact of anthropogenic hydrocarbons in the aquatic environment, with particular reference to new synthetic hydrocarbons;

(i) further study of the biological effects of oil based muds and various drilling additives;

(j) studies on contamination by, and effects of, PAHs in harbours, estuaries and other nearshore areas; and

(k) development of an acceptable monitoring and assessment program for marine ecosystem impacts arising from projected large scale hydrocarbon development in the Atlantic offshore.

(l) enhanced effort to develop fisheries information systems and sensitivity maps, in support of contingency planning;

(m) implementation of recommendations of the West Coast Offshore Exploration Panel, with particular emphasis on:

  - development of DFO programs and expertise needed to participate effectively in future regulatory processes for offshore drilling and to be able to respond to oil spill emergencies;
  - development of a research capability within the DFO Pacific Region (particularly respecting potential sublethal effects upon juvenile salmon);
  - studies of currents and waves and development of oil an spill trajectory modelling capability applicable to the Northern B.C. Coast; and
  - resource inventories and sensitivity mapping within the 20 km drilling exclusion zone.

Finally, in spite of the fact that DFO programs have been fairly responsive to client needs, the clients themselves have identified a need for better, direct consultation, improved delivery of information and increased program collaboration. Possible improvements include:

- participation and presentation of papers at national workshops, with special emphasis on joint government and industry fora such as the AMOP (DOE), Fairmont (industry) and Aquatic Toxicity (DFO) workshops;

- participation in and support of international conferences, such as the 1988 International Conference on Drilling Wastes;

- contributions of appropriate articles on DFO work to industry journals and newsletters, such as those of the Canadian Petroleum Association;
- participation on government/industry working groups;
- direct collaboration with industry on research and monitoring programs;
- participation on the Environmental Studies Research Fund Management Board and related committee infrastructure (program study committees and contract advisors);
- participation in the energy R&D program and related workshops;
- highlight programs and results in inhouse DFO newsletters; and
- preparation of fact sheets and press kits.

## APPENDIX A - PART 1

## LIST OF CLIENTS INTERVIEWED

(1) Newfoundland and Labrador Offshore Petroleum Board -- Brian Power

(2) Canada Nova Scotia Oil and Gas Board -- Bob Bailey

(3) Department of Transport -- Tom Fleck, Mike Greenham, Pat Gibson, Ian Marr

(4) Department of Indian and Northern Affairs -- Ted Langtry, John Miller, David Stone

(5) Department of Environment -- Wayne Richardson, John Karau, Dave Thornton, Peter Wells

(6) Canada Oil and Gas Lands Administration -- Rainer Engelhardt, Ken Sato

(7) B.C. Ministry of Environment -- Bob Langford

(8) Alberta Department of Energy and Renewable Resources -- Ray Makowecki

(9) Dome Petroleum Ltd. -- Ed Pessah

Contacted but did not respond:

E. Birchard, Canadian Petroleum Association
C. Ross, Mobil Canada Ltd.

## APPENDIX A - PART 2

## LIST OF QUESTIONS POSED TO INTERVIEWEES

In relation to the Department of Fisheries and Oceans and its mandate and programmes relating to hydrocarbon pollution:

(a) In your view, what are the outstanding scientific issues relating to hydrocarbon pollution in the aquatic environment, both marine and freshwater?

(b) In your view, what is or should be the role of DFO in this field, respecting both research and effects monitoring?

(c) To what issues should DFO devote particular attention, both regionally and nationally? Are there issues that you feel DFO is neglecting? Are there issues towards which DFO may be devoting too much effort?

(d) Do you have particular projects that you would recommend as deserving DFO attention? And why?

(e) What measures should DFO be taking to ensure that its research results are made available and relevant to its clients and users? Are you receiving adequate service from DFO?

(f) In light of today's fiscal climate, do you have any suggestions which would assist DFO in developing a long term research and monitoring strategy?

(g) Are there any other comments or suggestions that you would like to make relevant to the hydrocarbon pollution issue?

## APPENDIX A - PART 3

## SUMMARIES OF INDIVIDUAL INTERVIEWS

### INTERVIEW - Brian Power (Newfoundland Board)

Conducted by telephone.

In his view, the following are the main areas of research on which DFO should concentrate:

1. Fish Tainting. Information is needed on:

   (a) persistence of tainting - how long before it disappears from each commercial species of importance.

   (b) the concentrations of hydrocarbons which cause tainting, both in fish and in the water column.

   He is looking for a mechanism for predicting the size of an exclusion zone in the event of a spill (resulting from tainting and its potential effect on the market).

2. Impact Assessment. He is looking for predictive statements on the effect of a given quantity/concentration of oil on a fish population! He noted that DFO criticized Mobil at the Hibernia hearings for a lack of quantitative predictions and measurements.

3. Effects Monitoring. More knowledge is needed on effects of a spill on fish. Do fish avoid a contaminated area? At what concentration levels should we be concerned? To what degree will fish absorb and retain hydrocarbons and what will be the adverse effects on them? Again, he noted that DFO recommended at the Hibernia hearings that Mobil do work on several of these issues.

On question (e), Power urged DFO to do a better job of disseminating information on current research programs and on results from research studies. He suggested that the department needs more Dave Scarratts who are good at communication.

### INTERVIEW - Bob Bailey (Nova Scotia Board)

Conducted by telephone.

Responses to Questions

(a) Effect of hydrocarbons on eggs and larvae and implications for fish stocks.

In general, feels major issues have been addressed and sees no evidence of a really outstanding problem. Major job is one of interpretation and communication.

(b) Sees effects monitoring as role of regulatory agency. DFO should be involved - also COGLA.

(c) Georges Bank. Feels there has been much study of specific topics but we have little understanding of the overall system - relation of the circulation patterns to biological productivity.

(d) Georges Bank again.

(e) Says information on research work and results difficult to get hold of e.g. Georges Bank (was easier to obtain from U.S. colleagues).

(f) DFO needs to establish its own priorities. Effects on eggs and larvae and relation to recruitment the biggest concern.

Effects of oil-based muds on scallops.

In the future the effects of production systems will be of greater concern than exploration.

(g) Expressed real concern over DFO's role as an advocate for the fishing industry (recommended reading 'Fire and Water' by Ashley Schiff).

## INTERVIEW - Dept. of Transport

Present were:

Tom Fleck, Mike Greenham, Pat Gibson, Ian Marr.

The following points arose from the discussions:

1. REET. Coast Guard prefers to use REET as the source of coordinated scientific advice. Amongst the information needed is:
   (a) improved current studies - needed for effective spill tracking.
   (b) ecological mapping - sensitive areas should be identified and priorities assigned on a seasonal basis.
   (c) knowledge of fish stock levels - for decisions on the use of booms in emergencies and for assessing fishermens' claims.

2. Monitoring of the water column. An ongoing program of monitoring hydrocarbon levels in the water column would make it possible to assess if pollution controls are having a beneficial effect e.g. pursuant to the Canada Shipping Act and MARPOL.

3. Monitoring of other chemicals. This is particularly important in the Great Lakes where a significant quantity of chemicals is washed into the lakes through washing of ballast tanks.

4. Sensitive Seas issue. Areas where standards above those required under MARPOL are being identified. P.K. Mukherjee is responsible for this within DFO.

5. Effects monitoring in the Arctic. DFO should study oil levels adjacent to natural seeps to determine the tolerance of marine organisms to hydrocarbon pollution.

INTERVIEW - Canada Oil & Gas Lands Administration (COGLA)

Present were: Rainer Engelhardt, Ken Sato.

Responses to question:

(a) Rainer advised that he would provide us with a more detailed set of recommendations for specific studies. The following is a short list of topic headings:

- (i) Determination of residence of hydrocarbons in fish tissue - persistence, steady state levels, background levels etc.
- (ii) Fate and effects of aged petroleum products - substitution of hydrocarbons e.g. nitrogen-containing hydrocarbons which are toxic.
- (iii) Long term biological effects e.g. what is the significance of MFO effects with respect to disease resistance, decreased fecundity? This has not been studied in Canadian resource species.
- (iv) Ability to identify hydrocarbon contamination by source.
- (v) Dispersion of oil below the water surface. What happens to it?
- (vi) Development of current models for trajectory analysis e.g. Georges Bank, near-shore Pacific coast.
- (vii) Regionally the key areas are Georges Bank, Pacific Coast, Northern Hudson Bay (effects of contamination and disturbance on walrus) and Mackenzie River (use of oil-based muds, natural seeps, disposal of wastes).

(b)
- (i) basic research on resource species.
- (ii) monitoring - DFO for long term ecological.
  - operator for local effects.
- (iii) design of monitoring programs to be performed by industry - research needed as basis for this.

(c)
- (i) Sensitive area mapping.
- (ii) West coast salmon.
- (iii) Impacts on larval fish and eggs.
- (iv) West coast native fishery - measurement of fishery.

(d) Tainting of scallops, quahogs and lobsters (see work by Adam and Stein).

(e)
- (i) need more communication between DFO regions - evidence of a lack of exchange of ideas and information.
- (ii) need more public profile - communication with public on research.
- (iii) need an information window to research institutes e.g. Brian Nicholls.
- (iv) need more workshops on specific topic areas.
- (v) need better linkages with universities and DFO support for basic research.

(f) (i) need for closer coordination with client groups.
(ii) concern re new CODES in relation to regional needs and problems.

(g) COGLA is generally satisfied and feels relations with DFO are good. There is a concern that basic research may be downgraded in favour of more applied research.

INTERVIEW - Dept. of Indian Affairs & Northern Development (DIAND)

Present were: Ted Langtry, John Miller, David Stone.

The following points arose from the discussions:

1. Tainting is the biggest area of concern and more effort should be made on this topic.

2. Fingerprinting to identify the source of contamination needs further attention. e.g. Fort Good Hope - is Norman Wells the source or has pressurizing the wells increased the extent of natural seeps?

3. Effects. We can tell that an organism has been affected (MFO induction/metalthianines) but what does it mean to the animal?

4. Drilling additives. Need to examine their significance.

5. Ecosystems. Need better understanding of Arctic ecosystems in order to assess effect of contaminants on them.

6. Priorities. Beaufort Sea is considered to be more important than Lancaster Sound.

7. Responsibility for monitoring. Question of definition. Feel DOE should be responsible for minitoring and DFO for research in support of monitoring (provide scientific basis).

8. Noise. Identified question of noise created by the hydrocarbon industry and its effects on marine mammals as an ongoing issue.

9. Sources. River runoff was noted as a major source of hydrocarbons in the oceans. However, other pollutants may be of greater concern than oil.

10. Consultation. Felt that this has been less than adequate. There is a need for a government - industry committee for regular reassessment of the situation and establishment of priorities.

DFO has been slow to respond to fire-fighting situations such as Norman Wells/Fort Good Hope. On the whole the response has been better on the physical/chemical side than on the fisheries side. However, Rick Josephson has been a real plus. Individuals have often seemed willing but unable to deliver. There appears to be a lack of focus for Arctic matters and a lack of budget.

Concern was expressed concerning DFO's reorganization and its effect on service to DIAND.

## INTERVIEW - Ed Pessah (Dome Petroleum)

Conducted by telephone.

Ed Pessah expressed concern that DFO is on another exercise which raises significant questions but feels that we have failed to respond adequately to such questions in the past. He feels that DFO's legislative base does not provide adequate support to its research responsibilities. His major concern is one for DFO's mandate and how it is discharged.

Specific responses:

(a) DFO should be trying to address issues which will help it to provide a more balanced picture of hydrocarbon pollution. He sees underwater noise as an associated problem which is of great concern to Dome.

(b) DFO should monitor the effects of hydrocarbons on fish stocks. The kinds of research necessary to achieve this need careful definition, probably by means of tightly organized workshops which will challenge researchers.

(c) He suggests that lower level research managers need to devote more effort to defining research priorities. In his view, they are not selective enough and too ready to use a staple gun.

(d) DFO should devote more effort to establishing its own priorities.

(e) There is a need for a regular bibliography of current research projects and a need for much more and better communication with clients.

## INTERVIEW - Ray Makowecki (Alberta Fish & Wildlife Division)

Conducted by telephone.

Responses to questions:

(a) Major concern is long-term release of polysaturated and unsaturated hydrocarbons. Need to know where they go and what effects they have. Are they the cause of tumourous growths in fish?

Second concern is the need to reassess the standards for hydrocarbons in wastes and in tissues. There must be a direct relationship with adverse effect.

(b) DFO should be addressing the long term research issues. While the province has reduced its effort, it is still addressing most short term problems (e.g. through Alberta Environmental Centre).

(c) DFO emphasis should be on long-term research with national implications, with particular emphasis on marine and international spheres.

(d) Athabasca Delta study. Lyle Lockhart has been very helpful.

(e) Says he is not familiar with what DFO is doing in a broader sense and would like to see more and better communications so that he would know what we are doing and what is available.

(f) No view to express.

(g) Hopes to see a resolution of relative roles with respect to the Fisheries Act and specifically the fish habitat sections. He hopes that current negotiations are not with Alberta Environment but with Alberta Energy & Natural Resources.

## APPENDIX B

## SELECTED KEY REFERENCES

American Petroleum Institute. Proceedings of biennial Oil Spill Conferences, published every second year since 1969. (sponsored by American Petroleum Institute, U.S. Environmental Protection Agency, and U.S. Coast Guard) A.P.I. Washington.

Arctic Marine Oilspill Program (AMOP) Technical Seminar. Conference Proceedings published annually since 1978. Environment Canada, Conservation and Protection, Ottawa.

Borseth, A. (Ed.). 1983. Handbook of Polycyclic Aromatic Hydrocarbons. Marcel Dekker. 727 pp.

Engelhardt, F.R. (Ed.). 1985. Petroleum Effects in the Arctic Environment. Elsevier. 281 pp.

FEARO. 1978. Report of the Environmental Assessment Panel: Eastern Arctic Offshore Drilling, South Davis Strait Project Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1979. Report of the Environmental Assessment Panel: Lancaster Sound Drilling. Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1980. Report of the Environmental Assessment Panel: Arctic Pilot Project (Northern Component). Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1983. Report of the Environmental Assessment Panel: Venture Development Project. Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1984. Report of the Environmental Assessment Panel: Beaufort Sea Hydrocarbon Production and Transportation. Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1985. Report of the Environmental Assessment Panel: Hibernia Development Project. Federal Environmental Assessment Review Office, Ottawa.

FEARO. 1986. Report of the Environmental Assessment Panel: West Coast Offshore Hydrocarbon Exploration. Federal Environmental Assessment Review Office, Ottawa.

Hodgson, G.W., D.M. Stonkus and H.A. Sergy (Eds.). 1987. Arctic 40, Suppl 1: 1-279. (Special issue describing the Baffin Island Oil Spill Project).

Kraybill, H.F., C.J. Dawe, J.C. Harshbarger and R.G. Tardiff (Eds.). 1977. Aquatic Pollutants and Biologic Effects with Emphasis on Neoplasia. Ann. New York Acad. Sci. 298: 604 pp.

Middleditch, B.S. (Ed.). 1981. Environmental Effects of Offshore Oil Production - The Buccaneer Gas and Oil Field Study. Marine Science, Vol. 14. Plenum, 446 pp.

Müller, H. 1987. Hydrocarbons in the Freshwater Environment. A Literature Review. Arch. Hydrobiol. Beih. Ergebn. Limnol. 24: 1-69.

National Research Council (U.S.A.). Steering Committee for the Petroleum in the Marine Environment Update, Board on Ocean Science Policy, Ocean Sciences Board, Commission on Physical Sciences, Mathematics, and Resources. 1985. Oil in the Sea: Inputs, Fates and Effects. National Academy Press. 601 pp.

Vandermeulen, J.H. and S.E. Hrudey (Eds.). 1987. Oil in Freshwater. Chemistry, Biology, Countermeasure Technology. Proceedings of a Symposium on Oil Pollution in Freshwater, held in Edmonton, Alberta. Pergamon Press. 512 pp.

Wolfe, D.A. (Ed.). 1977. Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press. 478 pp.

# APPENDIX C

## PROJECT INVENTORY

PART 1 Listing of Project Titles

PART 2 Project Budgets

PART 3 Sources of Funding

PART 4 Geographic Applicability

PART 5 Scientific Aspects

PART 6 Project Sheets

## APPENDIX C - PART 1

## LISTING OF 1987/88 DFO HYDROCARBON PROJECTS (ESTIMATED)

| Project Number | Title |
|---|---|
| Central and Arctic Region | |
| C.1 | Biochemical monitoring - MFO Activity of Great Lakes Fish |
| C.2 | Tumor monitoring in Great Lakes fish |
| C.3 | Biochemical pathology, oil chemistry and toxicology |
| Scotia/Fundy Region | |
| S.1 | Oil trajectory analysis |
| S.2 | Hydrocarbon effects on capelin eggs and larvae |
| S.3 | Carcinogenic compounds in estuarine receiving waters contaminated with coal-tars |
| S.6 | Calibration of MFO system in winter flounder as an effects monitoring tool |
| S.9 | Petroleum hydrocarbon components |
| S.10 | Marine emergencies |
| S.12 | Enhanced biodegradation of petroleum in the marine environment |
| S.13 | Petroleum residues in the Eastern Canadian Arctic |
| S.16 | Petroleum hydrocarbon stress to fish |
| Pacific Region | |
| P.1 | Ocean enclosure experiment and modelling to assess fate of oil and dispersants |
| P.2 | Marine ecosystem enclosure experiment |
| P.3 | NOGAP - sources, sinks and standing crop of natural hydrocarbons on the Beaufort Shelf |
| Gulf Region | None |
| Quebec Region | None submitted, but hydrocarbon studies are incorporated within ongoing projects relating to organic matter and surveillance in the St. Lawrence River. |

## APPENDIX C - PART 2

## PROJECT BUDGETS (ESTIMATED FOR 1987/88)
(PYs and $1,000s)

| Project Number | PYs | Salary | O&M | Capital | Total |
|---|---|---|---|---|---|
| C.1 | .71 | 24 | 3 | - | 27 |
| C.2 | 1.60 | 54 | 9 | 4 | 67 |
| C.3 | 4.60 | 180 | 117 | 12 | 309 |
| S.1 | .30 | 13 | 180 | - | 193 |
| S.2 | .40 | 18 | 95 | - | 113 |
| S.3 | .15 | 7 | 85 | 15 | 107 |
| S.6 | .25 | 12 | 77 | - | 89 |
| S.9 | .50 | 25 | 3 | 1 | 29 |
| S.10 | .10 | 5 | 4 | - | 9 |
| S.12 | .50 | 20 | 38 | - | 58 |
| S.13 | 1.50 | 60 | 25 | 12 | 97 |
| S.16 | .50 | 25 | 86 | - | 111 |
| P.1 | 1.0 | 45 | - | - | 45 |
| P.2 | 1.0 | 50 | - | - | 50 |
| P.3 | 2.0 | 92 | 300 | - | 392 |
| N.1 | 4.0 | 150 | 77 | - | 227 |
| **Total** | **19.11** | **780** | **1,099** | **44** | **1,923** |

Note: Of the total $1,099K in O&M, approximately $172K is A-Base. The other 84% comes from "external funding".

## APPENDIX C - PART 3

## SOURCES OF FUNDING - 1987/88
($1,000s)

| Project Number | A-Base | PERD | NOGAP | Other |
|---|---|---|---|---|
| C.1 | 27 | - | - | - |
| C.2 | 67 | - | - | - |
| C.3 | 222 | - | - | 87 |
| S.1 | 49 | 144 | - | - |
| S.2 | 18 | 95 | - | - |
| S.3 | 7 | 100 | - | - |
| S.6 | 12 | 77 | - | - |
| S.9 | 29 | - | - | - |
| S.10 | 9 | - | - | - |
| S.12 | 20 | 38 | - | - |
| S.13 | 97 | - | - | - |
| S.16 | 25 | 86 | - | - |
| P.1 | 45 | - | - | - |
| P.2 | 50 | - | - | - |
| P.3 | 92 | - | 300 | - |
| N.1 | 212 | 15 | - | - |
| **Total** | 981 | 555 | 300 | 87 |
| | | | **Grand Total** | 1,923 |

## APPENDIX C - PART 4

## GEOGRAPHIC APPLICABILITY

| Project Number | Marine | | Freshwater | | General | |
|---|---|---|---|---|---|---|
| | PY | $K | PY | $K | PY | $K |
| C.1 | | | .71 | 27 | | |
| C.2 | | | 1.6 | 67 | | |
| C.3 | .46 | 31 | 3.22 | 216 | .92 | 62 |
| S.1 | | | | | .30 | 193 |
| S.2 | .40 | 113 | | | | |
| S.3 | .08 | 54 | .07 | 53 | | |
| S.6 | .25 | 89 | | | | |
| S.9 | .50 | 29 | | | | |
| S.10 | .10 | 9 | | | | |
| S.12 | .50 | 58 | | | | |
| S.13 | 1.50 | 97 | | | | |
| S.16 | .25 | 56 | | | | |
| P.1 | 1.0 | 45 | | | | |
| P.2 | 1.0 | 50 | | | | |
| P.3 | 1.50 | 294 | .50 | 98 | | |
| N.1 | 4.0 | 227 | | | | |
| **Total** | 11.54 | 1,152 | 6.35 | 516 | 1.22 | 255 |
| | | 60% | | 27% | | 13% |

## APPENDIX C - PART 5

## SCIENTIFIC ASPECTS

| Project Number | Hydrocarbon Chemistry | | Analytical Methods | | Fate | | Effects | | Monitoring | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PY | $K | PY | $K | PY | $K | PY | $K | PY | $K |
| C.1 | - | - | .21 | 8.1 | - | - | .21 | 8.1 | .29 | 10.8 |
| C.2 | .08 | 3.3 | .08 | 3.3 | .08 | 3.3 | .88 | 36.8 | .48 | 20.3 |
| C.3 | .69 | 46.3 | .46 | 30.9 | .92 | 61.8 | 1.38 | 92.5 | 1.15 | 77.5 |
| S.1 | - | - | - | - | .30 | 193.0 | - | - | - | - |
| S.2 | - | - | - | - | - | - | .40 | 113.0 | - | - |
| S.3 | - | - | .03 | 21.4 | .06 | 42.8 | .06 | 42.8 | - | - |
| S.4 | X | | | | | | | | | |
| S.5 | X | | | | | | | | | |
| S.6 | - | - | .12 | 44.5 | - | - | .13 | 44.5 | - | - |
| S.7 | X | | | | | | | | | |
| S.8 | X | | | | | | | | | |
| S.9 | - | - | .25 | 15.0 | .12 | 7.0 | .13 | 7.0 | - | - |
| S.10 | - | - | - | - | .05 | 4.5 | .05 | 4.5 | - | - |
| S.11 | X | | | | | | | | | |
| S.12 | - | - | - | - | .40 | 11.6 | .10 | 46.4 | - | - |
| S.13 | - | - | - | - | 1.50 | 97.0 | - | - | - | - |
| S.14 | X | | | | | | | | | |
| S.15 | X | | | | | | | | | |
| S.16 | - | - | - | - | .50 | 111.0 | - | - | - | - |
| P.1 | - | - | .10 | 4.5 | .50 | 22.5 | .40 | 18.0 | - | - |
| P.2 | - | - | .05 | 2.5 | .75 | 37.5 | .20 | 10.0 | - | - |
| P.3 | .10 | 19.6 | .30 | 58.8 | 1.60 | 313.6 | - | - | - | - |
| N.1 | .40 | 22.7 | - | - | - | - | 2.8 | 158.9 | .8 | 45.4 |
| **Total** | 1.27 | 91.9 | 1.6 | 189.0 | 6.78 | 906.6 | 6.74 | 582.5 | 2.72 | 154.0 |

# PROJECT INVENTORY - HYDROCARBON POLLUTION

PROJECT TITLE: Biochemical Monitoring - Mixed Function Oxidase Activity of Great Lakes Fish
PROJECT LEADER: P.V. Hodson PROJECT NUMBER 024
Group: L.L. Luxon
Laboratory: Great Lakes Laboratory of Fisheries and Aquatic Science
DFO Region: Central and Arctic
Address: Canada Centre for Inland Waters,
Box 5050, Burlington, Ontario L7R 4A6
Telephone: (416) 336 4864

## OBJECTIVES

1. To develop a reliable and practical assay for mixed function oxidase activity in fish.
2. To adapt the assay for routine use in biological surveillance of chemical effects in Great Lakes fish.
3. To identify chemicals that induce MFO activity in Great Lakes Fish.

## RATIONALE

Laboratory measurements of the toxicity of chemicals to aquatic biota are the basis for water quality objectives. However, compliance with objectives may not protect biota from the interactive toxicity of mixtures or the effects of unknown or unmeasured chemicals. To ensure the validity of objectives, and to identify potential chemical problems in Great Lakes fisheries, this project will measure the degree of exposure of fish to polynuclear aromatic hydrocarbons through assays of their liver mixed function oxidase (MFO) activity. MFO activity is a measure of the rate of detoxification of aromatic chemicals; its elevation is associated with carcinogenicity and reproductive failure in fish. Development of an assay will address research needs for biological monitoring, polynuclear aromatic hydrocarbons (PAH) and fisheries rehabilitation (Hamilton Harbour) of the GLSAB, GLFC, the GLWQP chemical priority list and the 1978 Agreement on Great Lakes Water Quality.

## DESCRIPTION

This work will involve the following steps:

1. Modify sample collection, preservation and analytical techniques so that MFO activity can be measured reliably in feral fish.
2. Examine fish from areas of the Great Lakes showing high levels of contamination.
3. Conduct laboratory tests to identify interfering factors affecting MFO activity and causing ambiguity in conclusions.
4. Conduct laboratory tests to develop dose-response relationships that permit interpretation of field data on tissue residues and MFO activity.
5. Measure tissue residues of MFO-inducing compounds to identify potential chemical problems.

The following work has been accomplished:
(a) A simple but reliable assay was developed for measuring the activity of Aryl hydrocarbon hydroxylase (AHH) in livers of fish. The conditions of sampling, sample handling, sample storage and the assay itself were investigated and the method modified to avoid confounding factors.
(b) Studies of Great Lakes lake trout have demonstrated a strong geographical trend in AHH activity suggesting high levels of contamination and effects in Lake Ontario relative to the other Great Lakes. There was a significant temporal trend as well, since AHH activity declined to control levels during spawning, even in Lake Ontario. The cause was likely an inhibition of AHH enzymes by estradiol, a reproductive hormone. A MS describing these results has been submitted for publication.
(c) Parallel studies of white suckers (Catostomus commersoni) during the Spring or early summer failed to show geographical variations within Lake Ontario, despite high levels of contamination by PAH compounds in specific locations such as Hamilton Harbour. This may have been due to hormonal inhibition of AHH induction since white sucker are spring spawners. Therefore, further samples were collected in Hamilton Harbour in the Spring and Fall of 1986 to test the hypothesis that AHH activities were inducible and that endogenous activity would reflect local contamination if fish were sampled outside the spawning period. Endogenous activities were measured in white sucker, carp (Cyprinus carpio) and brown bullhead (Ictalurus nebulosus). Additional samples were taken to test inducibility by injection with beta-naphthoflavone. Preliminary results confirmed low AHH activity during the spring when spawning occurs in all species. Activity was higher in suckers in the Fall and they became quite inducible but the other two species remained unresponsive. While the hypothesis was supported for white sucker, further work is needed on factors affecting AHH activity in the other two species (MS in preparation)
(d) Additional research on methods to preserve liver samples was also conducted in 1986/87. The intent was to make sample collection more convenient and to avoid loss of activity between collection and analysis. These results indicate that livers must be homogenized and centrifuged shortly after fish are sampled. Freezing of the supernatants at -85 C should preserve AHH activity for up to 10 days, allowing analyses in the laboratory rather than in the field.
(e) Research in 1987/88 will involve a cooperative experiment with Dr. J. Carey, Environment Canada, to measure and correlate chemical residues in fish (particularly PAH and metabolites) and AHH activity. The populations sampled will be those exhibiting normal and abnormal reproduction since there may be a chemical basis for reproductive failure in the Great Lakes. Results of AHH assays will be cross-referenced to those of Lyle Lockhart, FWI.

PROJECT DURATION: 4TH year of 6

## EXPECTED UTILIZATION OF RESULTS

1. Input to the development biological monitoring programs of DFO (GLLFAS, Central and Arctic Region) and Environment Canada, (IWD).
2. Response to research needs for methods for biological monitoring of the IJC, GLFC, DFO and Environment Canada.
3. Response to research needs concerning the significance of PAH contamination of the Great Lakes, reproductive failure of Lake Trout, and rehabilitation of fish habitat and areas of concern (Hamilton Harbour) of the IJC, GLFC, Env. Canada, DFO and OMNR.

## PROGRAM RESOURCES

|  |  | 1986/87 | Actual | 1986/87 Adjusted |
|---|---|---|---|---|
| A-Base | PY | 0.4 | 0.7[1] |  |
| Program Resources | Sal | 18.0 | 24.0 |  |
|  | O&M | 2.5 | 2.5 |  |
|  | Cap | - | - |  |
|  | Total | 20.5 | 26.5 |  |
| Other resources |  | None |  |  |

[1] Hodson 0.1; Luxon 0.6

## CLASSIFICATION

Percent Relevance to

|  |  |
|---|---|
| - Chemistry of Hydrocarbons | 0 |
| - Analytical Methods | 30 |
| - Fate | 0 |
| - Effects | 30 |
| - Monitoring | 40 |
|  | 100 |

|  |  |
|---|---|
| - Freshwater | 100 |
| - Marine | 0 |
| - General | 0 |
|  | 100 |

PROJECT INVENTORY - HYDROCARBON ANALYSIS

PROJECT LEADER: V.W. Cairns
PROJECT TITLE Tumour monitoring in great lakes fish
GROUP: Fish Habitat Studies Division
LABORATORY: Great Lakes Laboratory for Fisheries and Aquatic Science
ADDRESS: 867 Lakeshore Road, Burlington, Ontario. L7R 4A6
TELEPHONE: 416 336 4862

OBJECTIVES:

1. To determine the distribution of PAH's, particularly those that are known carcinogens, in Hamilton Harbour surficial sediments.

2. To determine the relationship between sediment PAH concentrations and the prevalence of benign and malignant tumours in white suckers from Lake Ontario.

3. To determine if PAH's in extracts of sediments from Hamilton Harbour, Sixteen Mile Creek (both Lake Ontario sites), and South Bay (lake Huron) can induce and/or promote liver tumors in rainbow trout.

RATIONALE:

Surveys of white suckers and brown bullheads from Hamilton Harbour at the western end of Lake Ontario indicate that these fish are affected with benign lip papillomas, benign and malignant epidermal tumours, and hepatocellular and cholangiolar carcinomas. The Harbour receives effluent from four municipal treatment plants nd two major steel manufacturers. Both of these industries have coking facilities that historically discharged directly into the Harbour. These effluents now receive in-plant treatment and are discharged into the Harbour via the municipal treatment plants. Sediments in Hamilton Harbour are heavily contaminated with PAH's. Concentrations of Benzo (a) Pyrene, a recognized mammalian carcinogen, average 3 ppm and range from .2 to 20 ppm in Hamilton Harbour sediments. In addition, Hamilton Harbour sediments exceed open water dredge spoil disposal guidelines for chlorinated organics and metals. This research will address the relationship between sediment contamination and the prevalence of epidermal and hepatic tumours and possible effects of tumours on the structure of white sucker populations from Hamilton Harbour.

DESCRIPTION:

This project is in the 6th year of a 7 year program. Initial efforts concentrated on the prevalence of external lesions on the lips and body of white suckers from Hamilton Harbour. All of the lip lesions were characterized as benign papillomas. Lesions on the body included benign papillomas, benign dermal fibromas, and malignant squamous cell carcinomas. Papilloma frequency was age dependent and the frequency of occurrence averaged 39 per cent for fish greater than 5 years of age. The spawning population was tagged and monitored for three years to determine if these lesions had any effect on mortality rates, fecundity, growth, and behaviour. Results from these studies indicated that the tumours developed rapidly and remained on the fish for at least two years and probably for life. There were no adverse effects on fecundity or on reproductive success. Growth data suggests that older fish with tumors may not grow as rapidly as non tumoured fish. Previous studies suggested that these lesions were highest in Hamilton Harbour and declined with distance from the harbour. The geographical distribution of external lesions was determined in the third year of the project. Suckers from seventeen sites were monitored. Papilloma frequency in white suckers from Lake Simcoe, Sixteen Mile Creek, Humber River, Grahams Creek, and the Maitland River on Lake Huron was equal or exceeded the prevalence in fish from Hamilton Harbour.

In addition to lip and body papillomas, the white suckers from Hamilton Harbour were also affected with severe gill hyperplasia, cardiac muscle degeneration, and a variety of liver lesions ranging from mild hepatocyte and cholangiolar hyperplasia to hepatocyte and cholangiolar carcinomas. The frequency of these lesions in white suckers from Hamilton Harbour was compared with the prevalence from Forty Mile Creek and Sixteen Mile Creek. Similar lesions were found at all sites suggesting that the lesions were common in western Lake Ontario and were not unique to the Harbour. However, the tagging program suggested that white suckers move at least forty km following spawning and interpretation of cause and effect data is complicated by unknown exposure regimes. Fish from other sites in the western end of the lake may also be exposed to Harbour contaminants.

More detailed work in 1985 characterized the age distribution of the various hepatic lesions in white suckers from Sixteen Mile Creek and compared this with lesions in fish from upper Lake Huron. Results clearly indicate that both the hepatocellular and cholangiolar lesions in Lake Ontario fish are more numerous and more severe. There were no hepatocellular carcinomas found in the Lake Huron fish.

The liver lesions found in Lake Ontario white suckers are histologically similar to carcinomas induced by PAH's in brown bullheads. A project was initiated in cooperation with Dr. Chris Metcalfe, from Trent University, to determine if contaminated sediments in Hamilton Harbour were capable of initiating and promoting hepatocellular tumours. Developing fry were injected with small amounts of sediment extract from Hamilton Harbour, Sixteen Mile Creek, and South Bay. Aflatoxin was used as a positive control. This study is not complete. The fish were exposed in October, 1985 and will be sampled in February, 1987. A preliminary concentration (to determine the success of the injection technique) was analyzed in August of this year. Twenty two per cent of the fish exposed to aflatoxin and eight per cent exposed to Hamilton sediment extract have developed liver tumours. The control fish have no tumours. These data suggest the need for more definitive studies to determine what chemicals in the Hamilton sediments are responsible for tumour initiation and effective concentrations. There is also a need to establish a database describing the extent of liver tumour distribution in the Great Lakes, particularly in the Lake Ontario watershed.

EXPECTED UTILIZATION OF RESULTS:

1. Development of a tumour database to establish a baseline for future work and identify areas of concern.

2. To determine what chemicals in Hamilton Harbour sediments are responsible for tumour initiation and to determine the effective concentration.

3. To determine the relevance of pathological monitoring as a surveillance tool for measuring the effects of deteriorating habitat on Great LAkes fish.

PROGRAM RESOURCES:

| | 1986-87 |
|---|---|
| A BASE | 8.5K |
| PY | 1.6 |
| SALARY | 54K |
| CAPITAL | 4.5 |
| TOTAL | 67K |

CLASSIFICATION:

PER CENT RELEVANCE TO:

| | |
|---|---|
| -CHEMISTRY OF HYDROCARBONS | 5 |
| -ANALYTICAL METHODS | 5 |
| -FATE | 5 |
| -EFFECTS | 55 |
| -MONITORING | 30 |

FWI, Chemistry Section, Nov. 1986

## PROJECT INVENTORY - HYDROCARBON POLLUTION

| | | | |
|---|---|---|---|
| **Project Title:** | Biochemical pathology<br>Oil chemistry & toxicology | **Project Number:** | 4240-403<br>4240-404 |

**Project Leader:**
Name: W.L.Lockhart
Group: D.A. Metner, D.A.J. Murray, B.N. Billeck and R.A. Danell
Laboratory: Freshwater Institute
DFO Region: Central and Arctic
Address: 501 University Cr., Winnipeg, MB., R3T 2N6
Telephone: (204) 949-7113

**Objectives:** To conduct research on the responses (generally but not exclusively, sub-lethal) of aquatic animals and plants to chemical pollutants, principally petroleum products and pesticides.

**Rationale:** This has been a long-standing project which was partially converted in 1981 from other contaminants (mainly pesticides) in order to accomodate some study of hydrocarbons and their effects as a result of the regional need for information on these subjects, particularly with hydrocarbon exploration and production in the western Arctic. The descriptions below apply to the period from 1982 to the present (Nov., 1986).

**Description:**

(a) OERD funding was provided for the first two years of a four-year study of MFO enzymes in marine mammals. Funding was cut after two years but the work is being completed as time permits. A publication should be submitted by summer of 1987 describing the induction of three MFO enzyme activities in young harp seals treated experimentally with Norman Wells crude oil. Some of the work has been described at conference presentations at SETAC and at the Aquatic Toxicity Workshop. The focus of this OERD work was adaptation of suitable methods for reliable measurement of MFO enzymes.

(b) Some early work was done to describe the effect of Dome's Nektoralik oil on aquatic plants (culture growth in duckweed); an unpublished report was prepared for Dome Petroleum. This led to inclusion of plant work in the Freshwater Oilspill Research Program work outlined below. Probably the effect of petroleum oils on these plants was physical rather than chemical.

(c) The Freshwater Oilspill Research Program provided support for two years (now completed) to conduct laboratory research on oil/dispersant mixtures. Two reports were submitted to Esso Resources, and these should result in two journal publications by late 1987, one describing effects of oil and oil:dispersant mixtures on duckweed (culture growth), and one describing chronic and sub-lethal effects of oil and oil:dispersant mixtures on larval fish (growth, edema, deformities, fin rot, death). Conference presentations describing some of this work have been given at the Aquatic Toxicity Workshop and at the Arctic Marine Oilspill Conference.

(d) Sampling was started to begin survey of baseline microsomal MFO enzyme activities in Arctic fish and of PAH residues as part of a larger survey of contaminants in Arctic fish; preliminary results were included in a report submitted to DIAND who provided the support through their NOGAP project.

(e) Research was started to describe abnormalities (watery whitefish muscle and small, discoloured burbot liver) from lower Mackenzie river fish, hypothesized to be related to expansion of oil production at Norman Wells (MFO, proximate composition, residues). A preliminary report was prepared for the Ft. Good Hope Coordinating Committee (DFO, DOE, DIAND, GNWT, DENE, ESSO) An abstract on some of the work has been submitted to ICES for its Arctic pollution conference next summer; preliminary data were presented at the Arctic Water Pollution Conf. IAWPRC; and at the Western Residue Analysts Workshop.)

(f) Research was conducted to describe the chemical persistence, toxicology and tainting properties of diesel fuel following a spill which resulted in under-ice contamination of the Cameron River (NWT). The work was used in support of court prosecution of the company responsible for the spill, and a paper describing this case has been through internal review and should be submitted to a journal before the end of the year. A copy of the MS was given to the chairman at the Oct. meeting.

(g) Research to describe the chemistry, toxicology and tainting properties of effluent from the Suncor oil-sand plant was conducted (initially at the request of Health and Welfare, Medical Services, Edmonton) following a spill under the ice-covered Athabasca River in the winter of 1982, and the results were used in a series of Fisheries Act prosecutions by the Government of Alberta.

(h) The laboratory has participated in several DOE and IJC check sample programs for analysis of polyaromatic hydrocarbons (using HPLC), with encouraging results. The methods have been applied to begin examination of Arctic sediments (Bent Horn) and fish for their PAH content. Several PAH are generally detectable in the low ppb range. The sediment results were included in a report by LGL Ltd. to DIAND, and fish results have been included in reports to DIAND (see d and e above). Some of this work was presented at the Chemical Institute of Canada Symposium on Arctic pollution.

(i) Oil-tainting experiments have been carried out jointly with Roberta York from the DFO Inspection lab on Suncor effluent, Cameron River diesel and Norman Wells crude oil, using whitefish, trout, and Arctic char. A paper describing the work is being given by Roberta at a Food Technology symposium in Alaska this month (Nov., 1986).

FWI, Chemistry Section, Nov. 1986

(j) A partitioning method for the analysis of "water soluble fraction" of oils has been adapted and applied to measures of exposure in bioassays. A paper was published describing the analysis and a copy was given to the chairman at the Oct. meeting.

(k) The experience with the Suncor and Cameron River samples led to an investigation of the role of aeration in bioassay tests (removes volatiles and toxicity). A paper describing these results is in press in "Oil and Freshwater" and a copy was given to the chairman at the Oct. meeting. It is argued that the aeration of regulatory bioassays introduces a serious bias in describing the toxicity of effluents to be released under ice.

(l) An air-extraction technique for the analysis of low-boiling hydrocarbons in fish tissues has been applied to fish from Ft. Good Hope and other northern fish; it indicates very widespread presence of low ppb levels of ethylbenzene and xylenes in the fish (possibly by LRTAP), with the liklihood of a second source within the Mackenzie River. The source in the river seems only to be significant in winter and it seems to provide hydrocarbons at Ft. Good Hope but not at Ft. Simpson (presumably Norman Wells). This is consistent with volatilization of these compounds during the open-water season but entrapment and downstream movement of them during winter.

(m) A small NOGAP project is underway to examine the effect (if any) on the salinity tolerance of young broad whitefish, starting with establishment of a laboratory stock of the species (which seems to have been successful) and then examining the effect of pre-exposure to oil on ability to stand a transfer to salt water. (These fish move back and forth among sites in the Mackenzie River and other streams along the Beaufort Sea coast, which reguires the ability to survive in a wide range of salinities.)

(n) Bioassays are being done to identify those process streams from Syncrude with greatest toxicity to fish, for comparison with results from Beckman "microtox" tests and with chemical characterizations by EPS (Edmonton).

Project Duration: 1981 - present (expected to continue for some time)

Expected Utilization of Results: Judging from experience to date, there seems to interest in the work from scientific agencies (reprints, invitations to present the work), from regulatory and resource management agencies (DFO operations, EPS, GNWT, Alberta Fish and Wildlife, Sask. Renewable Resources, Manitoba Fisheries Branch, Parks Canada), from law enforcement agencies (Alberta Attourney General's Dept., Dept. of Justice (Yellowknife), Dept. of Justice, (Saskatoon), from economic development agencies (DIAND), and from health agencies (Medical Services Branches, Edmonton and Yellowknife) and from private business (Esso Resources).

We plan continued work on oil sands effluents (joint with EPS, Edmonton) and further tainting studies (with DFO-Operations), and on MFO and hydrocarbon residues in northern fish and marine mammals. We also plan to apply some of the analyses to a Fraser River project jointly with DFO-Pacific staff this winter (H. Rogers), and possibly to begin some joint work with other regional projects on Lake trout MFO in the Great Lakes. We currently have live burbot and whitefish on hand for starvation and MFO induction experiments this winter. Three or four manuscripts should be prepared this winter (based on Freshwater Oilspill Research Program results, on oil-induction of MFO in young harp seals, and on tainting in Arctic charr and rainbow trout). Continuation of the Ft. Good Hope work will depend on the availability of external funds.

## Program Resources

| | | 1986/87 | Actual | 1986/87 Adjusted |
|---|---|---|---|---|
| A-Base | PY | 4.6[1] | | |
| Program Resources | Sal | 180 | | |
| | O&M | 30 | | |
| | Cap | 12 | | |
| | Total | 222 | | |
| Other Resources: | DIAND | 60 | | |
| | DFO-Ops | 22 | | |
| | NOGAP | 5 | | |
| | DOE | ? (5) | | |
| **Grand Total** | | 309 (+) | | |

[1] Lockhart 0.6; Metner 1.0; Murray 1.0; Billeck 1.0; Danell 1.0

## Classification:

Percent Relevance To:

| | | |
|---|---|---|
| - Chemistry of hydrocarbons | 15 | (d,e,f) |
| - Analytical methods | 10 | (a,d,e,f,g,h,j,l) |
| - Fate | 20 | (d,e,f,l) |
| - Effects | 30 | (a,b,c,d,f,g,i,k,m,n) |
| - Monitoring | 25 | (a,b,c,d,f,h,k) |
| | 100 | |

| | | |
|---|---|---|
| - Freshwater | 70 | (b,c,e,f,g,h,i,k,m,n) |
| - Marine water | 10 | (a,d,h,i,m) |
| - General | 20 | (a,f,h,j) |
| | 100 | |

FWI, Chemistry Section, Nov. 1986

| | | |
|---|---|---|
| -Site Specific (specify) | f | (Cameron River diesel spill) |
| | g | (Suncor effluent) |
| | n | (Bioassays of Syncrude process streams) |
| -Species specific | a | (Marine mammal MFO) |
| | e | (Northern burbot and whitefish quality) |
| | m | (Oil and salinity tolerance in whitefish) |
| -Regional | d | (Arctic fish MFO and PAH) |
| -Generic | b | (Effects of oil on aquatic plants) |
| | c | (Effects of oil/dispersant mixtures) |
| | h | (PAH analysis/residues) |
| | i | (Oil-tainting of fish) |
| | j | (Analysis of 'water soluble fraction') |
| | k | (Bioassays for ice-covered waters) |
| | l | (Low-boiling hydrocarbons in fish) |

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Oil Trajectory Analysis Project Number: A.9

Project Leader: D. J. Lawrence
Coastal Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-2431

Objectives: To improve our capability to track and predict the movement of oil on the continental shelf. The field program and data reduction related to the Kurdistan spill is complete. The results from a simple model to simulate slick movement during the first month following the spill have been published and interpretation of the oil distributions for the duration of the incident have been reported to Coast Guard. A prototype drifter hull has been developed and tested and the technology is being transferred to the private sector.

Rationale: Following major oil spills on the east coast (e.g. Arrow, Kurdistan) it was realized that our capability to predict the movement of the spilled oil was not adequate. Reasonable predictions of movement must be based on a more realistic model which accounts for the numerous forcing functions, including currents, waves and wind stress. Relevant data bases have to be identified or developed and translated into a suitable format. There was also a need for drifters which would more accurately track slick movement.

Description: An oil spill trajectory model has been developed which is more complex and accurate than the present working model maintained by AES. The model requires site specific data while the existing AES model is more general in its application. A prototype drifter hull has been developed to track oil slicks and with the help of PERD funding and Coast Guard support, evaluation of the drifter's performance has been completed. The prototype hull shape is being turned into a commercial prototype by means of an Unsolicited Proposal from Seimac Ltd.

Project Duration: 1979 - present

Expected Utilization of Results: Coast Guard, AES, proponents of offshore hydrocarbon exploration and development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.3 | 0.3 |
| Program Resources | Sal | 13 | 13 |
| | O&M | 36 | 36 |
| | Cap | | |
| | Total | 49 | 49 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | O&M | 44 | 144 |
| | Cap | 3.4 | |
| | Total | 47.4 | |

Grand Total:

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.3 | 0.3 |
| Resources | Sal | 13 |
| O&M | 80 | 180 |
| Cap | | |
| Total | 96.4 | 193 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 100 |
| Effects | |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | |
| General | 100 |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Hydrocarbon effects on capelin eggs and larvae    Project Number:PERD-N

Project Leader:K. T. Frank
Fisheries Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3498

Objectives: To provide information on the direct and indirect effects of Hibernia crude oil on capelin, one of the most ecologically important fishery stocks on the Grand Banks.

Rationale: Oil released into seawater concentrates in shallow water and the intertidal zone, the principal location of capelin spawning in waters of Atlantic Canada. Capelin is probably one of the most ecologically important species on the Grand Banks. Laboratory studies have shown that the egg and larval stages are highly susceptible to the chemical effects of oil. The susceptibility of capelin to the effects of oil stems from its use of beaches and shoal waters as spawning and egg incubation sites. The available oil spill trajectory estimates suggest that a slick generated in the Hibernia region has a high probability of reaching the Southeast Shoal, a known spawning area for capelin stocks of commercial significance. This study will quantify the threat of waxy crude oil typical of the Hibernia site to the well-being of capelin stocks in Newfoundland.

Description: To quantify the effects of oil intensity on egg mortality and hatching time. To assess the effects of oiling intensity on larval development, growth efficiency, activity level and mortality rates during the interval between hatching and dispersal to the aquatic environment. To determine oil-induced changes in sediment porosity and physical stabilization of beach sediments and to quantify the effect of physical stabilization on the dispersal rate of larvae from the sediments. To conduct field-based mesocosm studies to assess swimming performance, feeding success and predator avoidance of pelagic larvae incubated from oil contaminated sediments.

Project Duration: 1987-1990

Expected Utilization of Results:

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base Program Resources | PY | | 0.4 |
| | Sal | | 18 |
| | O&M | | |
| | Cap | | |
| | Total | | 18 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | | 95 |
| | Cap | | |
| | Total | | 95 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | | 0.4 |
| Sal | | 18 |
| O&M | | 95 |
| Cap | | |
| Total | | 117 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | |
| Effects | 100 |
| Monitoring | |
| | 100% |

| | |
|---|---|
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Regional - Scotia-Fundy/Newfoundland

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Carcinogenic compounds in estuarine receiving waters contaminated with coal-tars. Project Number:COAL

Project Leader:J. Vandermeulen
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-2479

Objectives: To quantify the impact and residence time of coal-derived tar components from a known mutagenic industrial effluent in an estuarine receiving water body. To measure tar contamination in the tissues of fish and shellfish from such waters. To assess sublethal effects using a suite of sublethal assays. To assess the incidence of tumors and cancers and other skin lesions characteristic of tar mutagens/carcinogens in a flounder population. To develop a model for long-term input of coal-derived tar waste from an industrial point-source, and to assess the carrying capacity of an estuarine receiving water body.

Rationale: Waste and other byproducts from synfuel industries are viewed with serious concern by epidemiologists and environmental experts because of their very high potent carcinogenic and/or mutagenic properties. Fish and other aquatic organisms taken from waters contaminated by synfuel PNA's and coal-tar wastes routinely show skin-lesions, lip tumors and other abnormalities. Recent evidence with a spill of such compounds from the Syncrude tar sand upgrading facility into a large northern Canadian river system demonstrated the vulnerability of fish to such contaminants. The extensive estuary near Sydney, N.S. is the receiving water body for a highly contaminated effluent draining from a large tar-pond located in one of its two arms, the South Arm. Concentrations of benzo(a)pyrene in tissue from lobsters caught in this area are among the highest recorded in the literature.

Description: This project will construct a model of the effluent and sediment transport in the estuary and assess the incidence of tumors in benthic fish. Toxicant (PNA, N-PNA, chlorobiphenyls, metals, selected co-contaminants) concentrations and distribution in sediments and water from the tar-pond, South Arm and greater estuary will be measured. Histopathological studies (incidence of tumors, lesions, tissue abnormalities) and sublethal physiological measurements (MFO, metabolic alterations) will be conducted on flounder and bivalves. The model will be used to estimate the carrying capacity of the estuary, residence times, contaminant hotspots and short and long-term impact on selected biota (flounder and bivalves).

Project Duration: 1987-1991

Expected Utilization of Results: environmental impact assessment

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | | 0.15 |
| Program Resources | Sal | | 7 |
| | O&M | | |
| | Cap | | |
| | Total | | 7 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 0 | 85 |
| | Cap | 0 | 15 |
| | Total | 0 | 100 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0 | 0.15 |
| Sal | 0 | 7 |
| O&M | 0 | 85 |
| Cap | 0 | 15 |
| Total | 0 | 107 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | 20 |
| Fate | 40 |
| Effects | 40 |
| Monitoring | |
| | 100% |
| Freshwater | 50 |
| Marine Water | 50 |
| General | |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Oil distribution in relation to winds and currents following the breakup of the Kurdistan

Project Number:F.8

Project Leader: R. Trites
Fisheries Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-2650

Objectives: To track the movement of the oil slick resulting from the breakup of the Kurdistan.

Rationale: The forces controlling the movement of oil slicks in the open ocean were poorly understood and it was often difficult to follow slicks at sea using conventional techniques. The Kurdistan spill provided an opportunity to develop and test new techniques for tracking and predicting the movement of slicks.

Description: A computer model was developed to predict the movement of the slick from the Kurdistan spill. The model is site and time specific using inputs of regional current, wave and wind data and comparing the results with observed slick movements and measurements of oil in the water column and oiling of coastlines. The results have been submitted to Atmosphere-Ocean as a manuscript entitled "Modelling oil movements from Kurdistan spill in Cabot Strait, Nova Scotia".

Project Duration: 1979 - 1986

Expected Utilization of Results: Closely coupled with project A.9

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.2 | 0 |
| Program Resources | Sal | 10. | 0 |
| | O&M | 1.2 | 0 |
| | Cap | | |
| | Total | 11.2 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.2 | 0 |
| Sal | 10. | 0 |
| O&M | 1.2 | 0 |
| Cap | | |
| Total | 11.2 | 0 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 100 |
| Effects | |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | |
| General | 100 |
| | 100% |

Site Specific - Cabot Strait, Nova Scotia

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Fate, metabolism, effects of petroleum hydrocarbons in marine environment

Project Number: H.3

Project Leader:J. Vandermeulen
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-2479

Objectives: To conduct long-term research into the fate, metabolism and effects of petroleum hydrocarbons in the marine environment. This research is carried out in concert with several larger projects (e.g. PERD67242 and PERD-JVnew).

Rationale: Residues from oil spills can persist in cold-water, low-energy environments for many years and these residues can have an effect on marine organisms. The long term fate of these residues and their effect at the ecosystem level is unknown. As a result a number of long term studies have originated from shorter term projects associated with the study of oil spills in eastern Canada and overseas. This research topic provides a reporting structure for these studies after the short term projects have been completed.

Description: This topic covers three sub-topics - long term fate of spilled petroleum hydrocarbons in water and coastal sediments, metabolism of hydrocarbons in fish by the mixed-function oxidase system, and mutagenic effects of water-borne environmentally available hydrocarbons. Several studies relating to the first sub-topic have been completed and reports have been published including three papers on the long-term fate of hydrocarbons in coastal sediments contaminated by the Amoco Cadiz supertanker spill in France. Long-term investigations into the fate of both high and low molecular weight hydrocarbons are underway Janvrin Lagoon, Chedabucto Bay, where hydrocarbons from the Arrow spill (1970) are still extant in shoreline sediments, and of which certain fractions have been found to be continuously bio-available to benthic bivalves. New analytical procedures for separating, identifying and monitoring high molecular weight hydrocarbons have been developed. Studies of metabolism of hydrocarbons in fish by the mixed-function oxidase system have continued and are summarized in a recent publication. A study of mutagenic effects of water-borne hydrocarbons has been completed and the results submitted for publication.

Project Duration: continuing

Expected Utilization of Results:government agencies, proponents of offshore development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 1.0 | 0 |
| Program Resources | Sal | 25 | 0 |
| | O&M | 8 | 0 |
| | Cap | | |
| | Total | 33 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 1.0 | 0 |
| Sal | 25 | 0 |
| O&M | 8 | 0 |
| Cap | | |
| Total | 33 | 0 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | 20 |
| Fate | 30 |
| Effects | 50 |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Site Specific - Brittany, France; Chedabucto Bay, N.S.
Generic - ~20%

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Calibration of MFO system in winter flounder as an effects monitoring tool Project Number:H.7

Project Leader:R.F. Addison / J. F. Payne
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3279

Objectives: To assess the value of MFO techniques as a monitoring tool of the effects of petroleum hydrocarbons on fish and invertebrates.

Rationale: The MFO induction technique has not yet found acceptance as a routine assay in biological effects monitoring. We believe this is because no single species has been studied with sufficient intensity to establish the range of natural variation with size, sex and season, against which MFO levels of specimens contaminated with oil can be judged.

Description: A two year study of natural variability of MFO enzyme levels in winter flounder has been completed thus providing a firm data base for comparative purposes. The inducibility of hepatic MFO activity by non-petroleum compounds has been studied and a dose-response relationship of MFO induction with petroleum exposure has been established (DFO Nfld. component). A practical manual for the routine use of the MFO assay has been prepared and a demonstration project is underway. The feasibility of the use of MFO induction methods with shellfish and other invertebrates will be studied.

Project Duration: 1983-1990

Expected Utilization of Results: industry and DOE-EPS

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.25 | 0.25 |
| Program Resources | Sal | 12 | 12 |
| | O&M | | |
| | Cap | | |
| | Total | 12 | 12 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 77 | 77 |
| | Cap | | |
| | Total | 77 | 77 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | .25 | .25 |
| Sal | 12 | 12 |
| O&M | 77 | 77 |
| Cap | | |
| Total | 89 | 89 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | 50 |
| Fate | |
| Effects | 50 |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title:Chemical pathways of environmental degradation of oil Project Number:I.19

Project Leader:P. M. Strain
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-7177

Objectives: Residues from heavy oil stranded on low-energy sandy beaches can persist for many years in the intertidal zone. While it has been hypothesized that lighter oils such as the Venture condensates would be rapidly dispersed even in a cold, low-energy environment there was no data to support the hypothesis.

Rationale: In the event of offshore production of oil and gas on Canada's east coast continental shelf, large volumes of hydrocarbons will be moved through the coastal zone by either tanker or pipeline. This project examined the behaviour of condensate from the Venture gas field on the Scotian Shelf in a sandy, low-energy beach.

Description: The fate of Venture condensate on a low-energy beach was followed for a period of more than a year. Rates of evaporation and dissolution were followed in the supra- and intertidal zones of the beach. It was found that biodegradation of the condensate was negligible and that dissolution rates were at least an order of magnitude less than those predicted. This project was completed with publication and presentation of the results in 1985/86.

Project Duration: 1983-1986

Expected Utilization of Results:proponents of offshore hydrocarbon exploration and development.

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 1.5 | 0 |
| Program Resources | Sal | 60 | 0 |
| | O&M | 2.8 | 0 |
| | Cap | 1.6 | 0 |
| | Total | 64.4 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 1.5 | 0 |
| Sal | 60 | 0 |
| O&M | 2.8 | 0 |
| Cap | 1.6 | 0 |
| Total | 64.4 | 0 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 100 |
| Effects | |
| Monitoring | |
| | 100% |
| Marine Water | |
| | 100% |

Generic

# PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Grand Banks Ecology: Ecosystem Modelling Project Number:K.2

Project Leader:W. Silvert
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-1577

Objectives: To design and develop through a series of workshops an ecosystem model of the Grand Banks and to use the model to identify potential impacts of oil spills in cases where supporting toxicological evidence for an effect has not been firmly established.

Rationale: Lethal and sub-lethal effects of petroleum hydrocarbons have been demonstrated for a number of marine organisms. The long term impact of these impacts on the ecosystem have not been studied. Large natural variations in biological variables make it impossible to separate natural and induced variations using tradition study techniques. Similarly it is hypothesized that the timing of a spill relative to critical biological events and the propagation of effects through the food chain may be very important. Construction of an ecosystem model provides a means of studying these interactions and also provides a framework for assessing results of and designing field studies.

Description: An ecosystem model of the Grand Banks of Newfoundland was developed using a series of interactive workshops. Data was extracted from past studies including the Mobil Oil environmental baseline study data base. Field studies were designed and conducted to fill some data gaps. The preliminary model was used to model interactions between biota and potential contaminants associated with petroleum resource development. Presently, the model is being evaluated for its suitability for application in impact assessment. This includes comparison with other approaches to ecosystem modelling as well as an analysis of cost effectiveness compared to conventional approaches.

Project Duration: 1983-1987

Expected Utilization of Results: federal and provincial agencies, proponents of offshore hydrocarbon development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.75 | 0 |
| Program Resources | Sal | 35 | 0 |
| | O&M | | |
| | Cap | | |
| | Total | 35 | 0 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 63 | 0 |
| | Cap | 5 | 0 |
| | Total | 68 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.75 | |
| Sal | 35 | |
| O&M | 63 | |
| Cap | 5 | |
| Total | 103 | |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | |
| Effects | 100 |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Site Specific - Grand Banks of Newfoundland
Generic - 50%

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title:Petroleum Hydrocarbon Components Project Number:K.3

Project Leader:E. M. Levy
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3658

Objectives: The identification of non-polar organic constituents in environmental samples. (see also K.5)

Rationale: To gain insight into the geochemical origin and the processes of weathering and other interactions in, and with, the environment of individual hydrocarbons and other components.

Description: Extracts of water samples collected from the continental shelf off Labrador were found to have very low levels of aliphatic, aromatic and polar constituents. An XAD-2 resin extraction column was therefore used to extract volumes in excess of 100 L from the Scott Inlet area off Baffin Island. The non-polar hydrocarbons have been extracted from the resin and analyzed by capilliary column gas chromatography and gas chromatography/mass spectrometry. Work continues on the development of a suitable sampling system to identify organic constituents in pristine waters such as those of the Labrador Strait.

Project Duration: continuing

Expected Utilization of Results:proponents of offshore development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.5 | 0.5 |
| Program Resources | Sal | 25 | 25 |
| | O&M | 2.8 | 2.8 |
| | Cap | 1.6 | 1.0 |
| | Total | 29.4 | 28.8 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.5 | 0.5 |
| Sal | 25 | 25 |
| O&M | 2.8 | 2.8 |
| Cap | 1.6 | 1.0 |
| Total | 29.4 | 28.8 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | 50 |
| Fate | 25 |
| Effects | 25 |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Marine Emergencies Project Number:K.16

Project Leader:E. M. Levy
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3658

Objectives: In the past assistance has been provided in dealing with major oil spills arising from tanker accidents and a gas blowout.

Rationale: To maintain an operational readiness to respond on very short notice to marine emergencies by providing expert scientific advice and by conducting appropriate supportive chemical investigations when needed.

Description: No environmental emergencies arose during 1985/86. Previous responses are reported under other topics.

Project Duration: continuing

Expected Utilization of Results: Coast Guard, DOE

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.1 | 0.1 |
| Program Resources | Sal | 5 | 5 |
| | O&M | 4.2 | 4.2 |
| | Cap | | |
| | Total | 9.2 | 9.2 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.1 | 0.1 |
| Sal | 5 | 5 |
| O&M | 4.2 | 4.2 |
| Cap | | |
| Total | 9.2 | 9.2 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 50 |
| Effects | 50 |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Regional - Scotia-Fundy

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Intercalibration of petroleum residues in the water column and sea surface microlayer

Project Number:K.19

Project Leader:E. M. Levy
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3658

Objectives: To analyse intercalibration samples provided by the IOC.

Description: No samples were distributed by the organizers and therefore this topic has been terminated.

Project Duration: 1984-1986

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.1 | 0 |
| Program Resources | Sal | 5 | 0 |
| | O&M | 3.6 | 0 |
| | Cap | | |
| | Total | 8.6 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.1 | 0 |
| Sal | 5 | 0 |
| O&M | 3.6 | 0 |
| Cap | | |
| Total | 8.6 | 0 |

Classification:

Percent Relevance To:

| | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | 100 |
| Fate | |
| Effects | |
| Monitoring | |
| | 100% |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Enhanced biodegradation of petroleum in the marine environment

Project Number:K.23

Project Leader:E. M. Levy
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3658

Objectives: To examine the rates and processes of the degradation of Scotian shelf condensate and of Hibernia crude oil by indigenous microorganisms under ambient conditions and to identify the rate-controlling factors. A strategy will be developed to enhance the rate of biodegradation of oils spilled in the marine environment.

Rationale: An earlier study (I.19) indicated that condensate and other light crude oils stranded in low-energy environments could persist for periods of several years and under the ambient conditions of Eastern Canada. Thus, it was clear that the environmental threat posed by the production of gas and condensate from the Scotian shelf might have been underestimated. Since accidents are inevitable, some means of enhancing the natural degradative processes would offer an environmentally sound means of dealing with a spill and reducing its impact on the environment.

Description: Laboratory and field studies are being conducted using Scotian Shelf condensate in an experimental sand column and in nitex bags on a low-energy sandy beach, respectively. A proprietary oleophilic nutrient microemulsion has been used to enhance biodegradation in both studies. Enhanced rates of biodegradation are only short lived in the natural environment. Studies are continuing on the effect of replenishing nutrients and in addition, tests will be conducted using a sample of Hibernia crude oil.

Project Duration: 1984-1990

Expected Utilization of Results: DOE, Coast Guard

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.5 | 0.5 |
| Program Resources | Sal | 20 | 20 |
| | O&M | | |
| | Cap | | |
| | Total | 20 | 20 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 64 | 38 |
| | Cap | 7.5 | |
| | Total | 71.5 | 38 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.5 | 0.5 |
| Sal | 20 | 20 |
| O&M | 64 | 38 |
| Cap | 7.5 | |
| Total | 91.5 | 58.5 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 80 |
| Effects | 20 |
| Monitoring | |
| | 100% |
| | |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

# PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title:Petroleum residues in the Eastern Canadian Arctic Project Number:K.5

Project Leader:E. M. Levy
Chemical Oceanography
Atlantic Oceanographic Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3658

Objectives: To determine the extent and fate of submarine oil seeps in the Scott Inlet area.

Rationale: Petroleum hydrocarbons enter the marine environment through natural processes as well as by chronic and accidental discharges. The magnitude and fate of this input is not adequately understood. Submarine seeps, previously identified in the Scott Inlet area off Baffin Island have been the subject of extensive studies. The availability of the submersible, PISCES IV, provided an opportunity to make some in situ observations of the seep and to collect carefully placed samples.

Description: A newly designed sampler was used to collect oil and gas escaping from the bottom and the gas was found to contain ethane and hydrogen sulfide. Samples of the "white, fuzzy slime" observed in the area of the seeps were collected and subjected to microbiological analysis. The material was identified as a filamentous bacteria. A small, controlled spill (4 liters of diesel oil containing a fluorescent dye) was conducted at the sea bottom (400 m) in the area of the seep to determine the fate of the oil from the seeps. The rate of ascent of this material to the surface was found to be slightly more than an hour. Numerous samples of seep material and wate column extracts were collected.

Project Duration: continuing

Expected Utilization of Results:proponents of offshore hydrocarbon development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 1.5 | 1.5 |
| Program Resources | Sal | 60 | 60 |
| | O&M | 24.5 | ? |
| | Cap | 12.3 | ? |
| | Total | 96.8 | ? |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 1.5 | 1.5 |
| Sal | 60 | 60 |
| O&M | 24.5 | ? |
| Cap | 12.3 | ? |
| Total | 96.8 | ? |

Classification:

Percent Relevance To:

| | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | 100 |
| Effects | |
| Monitoring | |
| | 100% |
| | |
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

# PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Sub-lethal effects of OBM cuttings Project Number:OBM

Project Leader:R.F. Addison / J.F. Payne
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-3279

Objectives: To expose commercially significant fish to a range of OBM cuttings to assess their effects on hepatic MFO induction. To sample flesh from experimentally exposed fish and commercially significant shellfish for contracted taste panel studies. To sample tissues from experimentally exposed fish and shellfish for contracted hydrocarbon residue analysis.

Rationale: Oil based drilling muds (OBM) have so far been used in the Canadian offshore only on an experimental basis, but it seems that several applications will be made tby East Coast offshore operators to use a range of OBM containing several types of base oils. There are three main questions about the use of OBM in the Canadian environment for which more information is desirable; these are

[1] What are the sub-lethal and long term effects of OBM discharges, especially on potentially sensitive marine species?
[2] What is the potential for tainting of commercial species caught in the vicinity of wells using OBM?
[3] How persistent are OBM discharges?
This project addresses points (a) and (b).

Description: Commercially significant fish and shellfish are exposed to a range of OBM cuttings to assess their effects on hepatic MFO induction. Samples of flesh from these fish and shellfish are subjected to taste panel studies and analysed for hydrocarbon residues.

Project Duration: 1985-1987

Expected Utilization of Results: government agencies and proponents of offshore hydrocarbon exploration and development

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.25 | |
| Program Resources | Sal | 12 | |
| | O&M | | |
| | Cap | | |
| | Total | 12 | |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 53 | |
| | Cap | | |
| | Total | 53 | |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.25 | |
| Sal | 12 | |
| O&M | 53 | |
| Cap | | |
| Total | 65 | |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | |
| Effects | 100 |
| Monitoring | |
| | 100% |

| | |
|---|---|
| Freshwater | |
| Marine Water | 100 |
| General | |
| | 100% |

Generic

# PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title:Risk assessment of toxic chemicals to fisheries. Project Number:464

Project Leader:J. F. Uthe
Fisheries and Environmental Science
Fisheries Environmental Research
Halifax Technology Laboratory
Scotia-Fundy Region
(902)-426-6277

Objectives: The general objectives are to carry out research into the nature and occurrence of chemical contaminants in marine biota, emphasizing those species of commercial interest. The research focuses on both human health and habitat protection aspects.

Rationale: The hydrocarbon aspect of this project is a very small part of a larger study to assess the impact of chemical contamination on marine resources in the region and to supply a focus for regional and supra-regional response on the effects of chemical contaminants on the commercial use of a variety of fishery products.

Description: The hydrocarbon related activity for this project is the study of polycyclic aromatic hydrocarbon contamination in lobsters caught in Sydney Harbour where the sediments and water are contaminated by runoff from residues from the coke ovens in Sydney. Levels of PAH in the lobster are sufficiently high that this fishery has been closed.

Project Duration: 1984 - present

Expected Utilization of Results: Fisheries Surveillance Branch

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.1 | 0 |
| Program Resources | Sal | 4 | 0 |
| | O&M | 1 | 0 |
| | Cap | | |
| | Total | 5 | 0 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.1 | 0 |
| Sal | 4 | 0 |
| O&M | 1 | 0 |
| Cap | | |
| Total | 5 | 0 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | |
| Effects | |
| Monitoring | 100 |
| | 100% |
| | |
| Freshwater | |
| Marine Water | |
| General | 100 |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

Project Title: Petroleum hydrocarbon stress to fish Project Number: Hxx

Project Leader:J. Vandermeulen
Environmental Oceanography
Marine Ecology Laboratory
Scotia-Fundy Region
Bedford Institute of Oceanography
(902)-426-2479

Objectives:

[1] To quantify tissue contamination for a representative juvenile fish as a function of concentration and exposure.
[2] To establish sublethal and lethal exposure thresholds in juvenile fish under realistic spill contamination conditions.
[3] To quantify hydrocarbon imposed sublethal stress in juvenile fish.
[4] To define tainting concentration thresholds.

Rationale: Information on hydrocarbon toxicity to fish stocks is essential and critical to decisions regarding oil and gas exploration in Canadian waters, and to environmental impact assessment of oil spills. Such information for economically significant fish stocks for the Canadian east coast is fragmented. Of particular concern are the highly sensitive juvenile stages. Integrated data on hydrocarbon exposure and physiological and pathological impact do not now exist for juveniles of any economically important fish species for Canadian east coast marine waters.

Description: The project is being carried out with juveniles of Atlantic salmon. Acute lethal concentrations will be determined as a function of age of juvenile salmon. The relationship between toxic and sublethal concentrations and exposure times will be investigated. Other aspects of the study include, effects of hydrocarbons on growth and development, physiological effects and biochemical studies (protein, lipid,energy (ATP) and metabolic measurements.

Project Duration: 1986-1990

Expected Utilization of Results: Industry, private sector and government agencies

Program Resources

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 0.75 | 0.5 |
| Program Resources | Sal | 32 | 25 |
| | O&M | | |
| | Cap | | |
| | Total | 32 | 25 |

Other Resources:

| | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| PERD | PY | | |
| | Sal | | |
| | O&M | 72 | 86 |
| | Cap | 15 | 0 |
| | Total | 87 | 86 |

Grand Total

| | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|
| PY | 0.75 | 0.5 |
| Sal | 32 | 25 |
| O&M | 72 | 86 |
| Cap | 15 | 0 |
| Total | 119 | 111 |

Classification:

| Percent Relevance To: | |
|---|---|
| Chemistry of Hydrocarbons | |
| Analytical Methods | |
| Fate | |
| Effects | 100 |
| Monitoring | |
| | 100% |
| Freshwater | 50 |
| Marine Water | 50 |
| General | |
| | 100% |

Generic

## PROJECT INVENTORY - HYDROCARBON POLLUTION

**Project Title:** Ocean Enclosure Experiment and Modelling to Assess Fate of Oil and Dispersants — Project #67240

**Project Leader:**
Dr. C.S. Wong
Ocean Chemistry Division
Hydrocarbons and Pesticides Lab
Pacific Region
Institute of Ocean Sciences
P.O. Box 6000, Sidney, B.C. V8L 4B2
Phone No.: 656-8407

**Objectives:**

1. To study the effectiveness/interaction of oil/dispersants in high silt water.
2. To quantify the biodegradation rates of oil in oil-based drilling muds under different environmental conditions.
3. To construct mathematical predictive models for such chemical/biochemical changes and interactions with environmental factors.

**Rationale:** Ocean Enclosed Experiments have been successfully applied by the Ocean Chemistry Division at the Institute of Ocean Sciences to fate and effects studies of toxic metals and hydrocarbons. Properly interpreted, the reults are often directly relevant to natural open ocean systems. Also, results can provide insights into laboratory studies that are relevant to the real world. From past experience, the objectives of this study are obtainable by the mesocosm approach.

**Description:** The approach will utilize large enclosures of sea water (200 L-65,000 L) with/without contact with sediment in a pan inside the plastic bags (2m x 18m) or in PVC tanks (0.5m x 1m) lined with precleaned plastic such as Teflon. Different environmental conditions will be used, eg., oxygenated/anoxic, high organic/nutrient-poor, varying quantity of silts or oil-based drilling muds.

**Expected utilization of results:** Clients: DFO, DOE, DIAND, GOGLA, oil industry, general scientific community.

| Program Resources: | | 1988/89 | 1989/90 | 1990/91 |
|---|---|---|---|---|
| A-Base | PY | 1 | 1 | 1/2 |
| | Sal | 45 K | 45 K | 28 K |
| | O&M | 0 | 0 | 0 |
| | Cap | 0 | 0 | 0 |
| | Total | 45 | 45 | 28 K |
| Other Resources | | | | |
| | OERD* | 172 K | 96 K | 20 K |
| Grand Total | | 217 K | 141 K | 48 K |

**Classification:**

| | |
|---|---|
| % relevance to | |
| Chemistry of HC | 0 |
| Analytical methods | 10 |
| Fate | 50 |
| Effects | 40 |
| Monitoring | 0 |

| | |
|---|---|
| - freshwater | |
| - marine water | 100 |
| - general | |

Site specific

| | |
|---|---|
| Regional | Arctic |
| Generic | × |

* Interim approval - subject to final approval

## PROJECT INVENTORY - HYDROCARBON POLLUTION

**Project Title:** Marine Ecosystem Enclosure Experiments - 86

**Project Leader:**
Dr. C.S. Wong
Ocean Chemistry division
Hydrocarbons and Pesticides Laboratory
Pacific Region
Institute of Ocean Sciences
P.O. Box 6000, Sidney, B.C. V8L 4B2
Phone No.: (604) 656-8407

**Objectives:**

1. Transfer to Chinese researchers of methods of using marine mesocosms (up to about 70 $M^3$ in size) for fate and effects studies of crude oils chemically disposed in sea water.
2. Publication of results in scientific literature.

**Rationale:** Mesocosms represent an intermediate state in scale and characteristics between the field and the laboratory. For fate and effects studies the field suffers from lack of control and difficulty in measurements. The laboratory suffers from the problem of questionable relevance to the real world. Mesocosms are a means of bridging the gap between to field and the laboratory.

**Description:** In China, (3rd Institute of Oceanography, Xiamen), MEE's (65 $m^3$) were used to study the fate and effects of a Chinese crude oil dispersed with Corexit 9527. In Canada (IOS, Sidney) smaller scale enclosures were used to study the effect of dispersing the same Chinese oil with Enersperse 700 and comparing this with that of dispersing Prudhoe Bay Crude Oil with Corexit 9527. The effect of the presence of certain added metals was also studies. A major focus of the study was on bacterial oil associations as observed by microscopy.

**Project Duration:** October 1985-November 1986.

**Expected Utilization of Results:** Clients: NBO (China), IDRC (Canada), DFO, DOE, DIAND, GOGLA, oil industry, general scientific community.

| **Program Resources:** | | 1986/87 |
|---|---|---|
| A-base | PY | 1 |
| | Sal | 50 K |
| | O&M | 0 |
| | Cap | 0 |
| | Total | 50 K |
| Other Resources | | |
| IDRC (Canada, NBO (China) | | 22 K |
| Grand Total | | 72 K |

**Classification:**

% relevance to

| | |
|---|---|
| - chemistry of HC | 0 |
| - anal. methods | 5 |
| - fate | 75 |
| - effects | 20 |
| - monitoring | 0 |

| | |
|---|---|
| - freshwater | 0 |
| - marine water | 100 |
| - general | 0 |

| | |
|---|---|
| Site specific | |
| Regional | |
| Generic | x |

Project P.3

## PROJECT INVENTORY - HYDROCARBON POLLUTION

**Project Title:** NOGAP B.6 - Hydrocarbon Component

**Project Leader:**
Dr. Walter J. Cretney (with Dr. Rob Macdonald)
Ocean Chemistry Division
Hydrocarbons and Pesticides Laboratory
Pacific Region
Institute of Ocean Sciences
P.O. Box 6000, Sidney, B.C. V8L 4B2
Phone No: (604) 656-8412

**Objectives:** Determination of sources, sinks and standing stock for natural hydrocarbons on the Beaufort Shelf.

**Rationale:** Following acute or chronic inputs of oils to an ecosystem the big question is: what are the likely effects? To answer this question, one must first know where the oil goes and how much it is in relation to the natural background. From studying transport sources, sinks and standing stock of natural hydrocarbons, information will be gained that will help in answering the questions where and how much.

**Description:** A cruise was conducted in September 1986 to collect some preliminary samples and test out some sophisticated equipment that will be used in future work. In January 1987, a cruise to the Fraser River estuary will be made to intercalibrate the various sampling techniques kthat will be used for hydrocarbons. There will be three field trips for through the to ice sampling and a final cruise in August 1987.

| **Program Resources:** | | 1986/87 | 1987/88 |
|---|---|---|---|
| A-base | PY | 1 | 2 |
| | Sal | 40 K | 92 K |
| | O&M | 0 | 0 |
| | Cap | 0 | 0 |
| | Total | 40 K | 92 K |
| Other Resources | | | |
| NOGAP | | 125 K | 300 K |
| Grand Total | | 165 K | 392 K |

**Classification**

| % relevance to: | |
|---|---|
| - chemistry of HC | 5 |
| - anal. methods | 15 |
| - fate | 80 |
| - effect | 0 |
| - monitoring | 0 |
| - freshwater | 25 |
| - marine water | 75 |
| - general | 0 |

Site specific :
Regional : Beaufort Shelf
Generic :

Project N.1

## PROJECT INVENTORY - HYDROCARBON POLLUTION

**Project Title:**

**Project No.:**

**Project Leader:** Name: Dr. Jerry F. Payne (contact)
Group: (Division or Section) Science Branch
Laboratory:
DFO Region: Newfoundland
Address: P.O. Box 5667, St. John's, Newfoundland
Telephone No.: (709) 772-2089 (2088)

**Objectives:** include any key milestones past or future (see Regional Overview)

**Rationale:** History if applicable, and past achievements
Context and reason for study (see Regional Overview)

**Description:**

**Project Duration:** state start-up date and end date, if applicable

**Expected Utilization of Results:** include key clients, relevance to other studies, etc.

| **Program Resources:** | | 1986/87 Actual | 1987/88 Adjusted |
|---|---|---|---|
| A-Base | PY | 4 | |
| | Sal | 150K | |
| | O&M | 62 | |
| | Cap | | |
| | Total | | |
| **Other Resources:** | | | |
| NOGAP | | 15K | |
| **Grand Total:** | | | |

**Classification:**

| % relevance to: | |
|---|---|
| - chemistry of HC | 10 |
| - anal. methods | |
| - fate | |
| - effects | 70 |
| - monitoring | 20 |

- freshwater
- marine water
- general